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Volume IV: Mobile Sources

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Procedures for Emission Inventory Preparation

Volume IV: Mobile Sources

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16. ABSTRACT

Procedures are described for compiling the complete comprehensive emission inventory of the criteria pollutants and pollutant sources. These procedures described are for use in the air quality management programs of state and local air pollution control agencies.

Basic emission inventory elements--planning, data collection, emission estimates, inventory file formatting, reporting and maintenance--are described. Prescribed methods are presented; optional methods are provided. The procedures are presented in five (5) volumes:

Volume I, Emission Inventory Fundamentals
Volume II, Point Sources
Volume III, Area Sources
Volume IV, Mobile Sources
Volume V, Bibliography

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NOTICE

The Procedures for Emission Inventory Preparation consists of these five volumes.

Volume I - Emission Inventory Fundamentals
Volume II - Point Sources
Volume III - Area Sources
Volume IV - Mobile Sources
Volume V - Bibliography

They are intended to present emission inventory procedures and techniques applicable in State and local air programs, and for contractors and other selected users. The object is to provide the best available and "state of the art" information. For some areas, however, the available source information and data either may allow more precise procedures and more accurate estimation of emissions or may not be amenable to the use of these procedures. Therefore, the user is asked to share his knowledge and experience by providing comments, successfully applied alternative methods or other emission inventory information useful to other users of these volumes. Please forward comments to the U.S. Environmental Protection Agency, Air Management Technology Branch, (MD-14), Research Triangle Park, NC 27711. Such responses will provide guidance for revisions and supplements to these volumes.

Other U.S. EPA emission inventory procedures publications:

Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume I, Second Edition, EPA-450/2-77-028, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1980.

Procedures for the Preparation of Emission Inventories of Volatile Organic Compounds, Volume II: Emission Inventory Requirements for Photochemical Air Quality Simulation Models, EPA-450/4-79-018, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

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Procedures for Emission Inventory Preparation

Volume IV: Mobile Sources

by

Monitoring and Data Analysis Division
Office of Air Quality Planning and Standards

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

September 1981

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1.0 INTRODUCTION

A fundamental requirement in the effort to control pollution of any form is to quantify the emissions being released. This is necessary in the context of both understanding the relationships between emission characteristics (rate, location, method of discharge, etc.) and resulting ambient concentrations, and developing appropriate policies and methods to ensure that ambient concentrations of the pollutant remain within acceptable limits. With regard to air pollution, specific requirements are set forth in Title 40, Code of Federal Regulations, Part 51.321 (40 CFR 51), and in the 1977 Amendments to the Clean Air Act for the development and maintenance of ongoing programs to inventory specific pollutant emissions. The requirements of 40 CFR 51 are for states to prepare and submit annual reports to the U.S. Environmental Protection Agency (EPA) regarding the emissions of particulate matter, sulfur oxides, carbon monoxide, nitrogen oxides, and hydrocarbons from point sources within their boundaries. The Amendments to the Clean Air Act, however, require the development of "...comprehensive, accurate, and current..." inventories from all sources of each pollutant for every nonattainment area, in conjunction with the preparation of revised State Implementation Plans (SIP). The implication, then, is that significant effort will continue to be expended on the development and maintenance of emission inventories to meet the requirements for both technical analysis and administrative reporting.

To assist the states in meeting the requirements for emission inventory development, a five-volume series has been prepared that describes in detail many of the technical aspects of the inventory process. This document is the fourth volume in the series, and focuses on the technical aspects of inventorying emissions from mobile sources. More specifically, this document presents an overview of the mobile source category as a whole and identifies specific methods that can be used to identify and inventory sources, estimate emissions, and establish and maintain a useful, current mobile source inventory file. In Chapter 2, the mobile source category is described in terms of the individual sources included, the significance of each source with respect to the mobile source category, the relative significance of the entire mobile source category with respect to other emission sources, and a general indication of the methods used to develop the inventory. Chapters 3 through 7 present specific methods that can be used to derive emission estimates for each of the primary mobile source subcategories. These subcategories and the report chapters in which they are presented are:

Off-highway Vehicles--Chapter 3

Highway Vehicles--Chapter 4

Aircraft--Chapter 5

Railroad Locomotives--Chapter 6

Vessels--Chapter 7

The other volumes in this Procedures for Emission Inventory Preparation series are:

Volume I--Emission Inventory Fundamentals

Volume II--Point Sources

Volume III--Area Sources

Volume V--Bibliography

Volume I is a guide to the managerial and technical aspects of the emission inventory. It outlines the informational sources available, methods of estimating emissions, data validation and quality assurance techniques as well as procedures to maintain and update the inventory. Also included are a detailed analysis of the manpower and resources required to derive each component of an emission inventory, and a comprehensive glossary.

Volume II assists the user in the identification of point sources, collection of data, calculation of emissions and data presentation. It establishes standardized methods and procedures so that the user can apply these methods to develop a point source data base.

Volume III outlines the methods of collecting and handling emission data from sources too small and/or too numerous to be surveyed individually--collectively known as area sources. Procedures are presented which will assist the user in identifying area source categories and important reference material which can be used to determine the activity levels associated with area source categories. Emission factors, emission calculations, pollutant allocation and projection techniques, and methods of data presentation are detailed to assist in the preparation and maintenance of the emission inventory of area source categories.

Volume V presents an extensive listing of reference material currently available in the literature which will assist the user in the development of the emission inventory. A concise abstract is provided for each reference cited, outlining the pertinent emission inventory information.

2.0 OVERVIEW OF THE MOBILE SOURCE CATEGORY

An inventory of pollutant emission sources should classify sources into two major categories--point sources and area sources. The point source category is described in detail in Volume II of this series.[1] The area source category is described in detail in Volume III of this series.[2] Mobile sources are a subcategory within the area source category of pollutant emission sources. However, the procedures for preparing and maintaining an inventory of emissions from mobile sources are presented herein, as a separate document in this series, because the procedures are uniquely different from those for other area source subcategories and because the mobile source inventory of emissions will represent a major portion of the total emissions of NO_x, HC and CO in any comprehensive emission inventory.

The mobile sources, for which inventory and emission calculation procedures are presented in this document, are off-highway vehicles and equipment, highway vehicles, aircraft, railroad locomotives, and vessels. The procedures are for calculation of tailpipe emissions and evaporative HC emissions (from the crankcases and vehicle fuel tanks) from these five mobile source categories. The emissions that result from tire wear, travel over roads or other surfaces, or vehicle fueling can be calculated from the procedures in Volume III of this series[2] and are specifically excluded from consideration in this document.

2.1 INDIVIDUAL MOBILE SOURCE CATEGORIES

The nature of mobile sources requires an understanding of the sources themselves and their activity before any attempt is made to calculate their emissions. The five mobile source categories are briefly characterized in this section.

2.1.1 OFF-HIGHWAY VEHICLES

This mobile source category includes a diverse set of source types. The movement of sources in this category occurs on surfaces other than the public highways. The total off-highway vehicle population can be characterized by six individual categories. They are:

(1) Farm equipment,

(2) Construction equipment,

(3) Industrial machinery,

(4) Motorcycles,

(5) Lawn and garden equipment, and

(6) Snowmobiles.

These are difficult categories to inventory because little data are available to determine their size or the operating characteristics of the sources in them. Chapter 3 of this document provides procedures for inventorying and estimating emissions from these categories.

2.1.2 HIGHWAY VEHICLES

This mobile source category includes all vehicles registered to use the public roadways. The predominant source in this category is the automobile. Trucks and buses are also included in this category. The total highway vehicle population can be characterized by eight individual vehicle-type categories. They are:

(1) Light-Duty Gasoline-Powered Vehicles (LDGV);

(2) Light-Duty Gasoline-Powered Trucks, up to 6000 lb gross vehicle weight (LDGT1);

(3) Light-Duty Gasoline-Powered Trucks, 6000 to 8500 lb gross vehicle weight (LDGT2);

(4) Heavy-Duty Gasoline-Powered Vehicles (HDGV);

(5) Light-Duty Diesel-Powered Vehicles (LDDV);

(6) Light-Duty Diesel-Powered Trucks (LDDT);

(7) Heavy-Duty Diesel-Powered Vehicles (HDDV); and

(8) Motorcycles (MC).

Automobiles will be classified into either category (1) or (5). Buses should be classified in categories (2), (3), (4), (6) or (7) depending on their gross vehicle weight and fuel type.

Numerous characteristics for each vehicle-type category are necessary before emissions can be calculated. These characteristics include, among others, vehicle, type, age distribution, annual mileage by vehicle type and age, and average speed by vehicle type. Chapter 4 of this document presents detailed procedures for identifying and using these and other key characteristics to calculate emissions.

2.1.3 AIRCRAFT

This mobile source category includes all types of aircraft whether civilian, commercial, or military. Emissions from idling, taxiing, and during landings and takeoffs are included. Landing and takeoff cycle (LTO) emissions are those that occur between ground level and an altitude of about 3000 feet.

The larger civil and commercial airports with continuously manned control towers maintain records of LTO cycles by type of aircraft as part of their standard operating procedure. Smaller airports also maintain these records to the extent that their control towers are manned or landing fees are recorded. Difficulty may be encountered in obtaining data on military aircraft operations at military airports.

The EPA has compiled a complete set of emission factors for the different types of aircraft operating in the different modes (i.e., idle, taxi, LTO). Chapter 5 of this document provides instruction on the methods of inventorying and calculating emissions from this mobile source category.

2.1.4 RAILROAD LOCOMOTIVES

This mobile source category includes all fossil fuel-fired locomotive engines operated on railways. The quantity of fuel used by locomotives and the size, in horsepower, of the locomotives are necessary data for emission calculations. Chapter 6 of this document provides detailed methods for calculating emissions from this mobile source category.

2.1.5 VESSELS

This mobile source category includes all sizes of self-propelled vessels. Two primary categories are considred--pleasure craft and commercial vessels. The commercial category includes all military and civilian vessels. For pleasure craft, the quantity of fuel, gasoline and diesel, used is applied to emission factors to yield emission estimates. Two subcategories of pleasure craft are considered--outboard and inboard. In general, direct estimates of fuel used for pleasure boating are not available. The procedures discussed in this document are based largely on deriving fuel use estimates as a function of the boat population and the water facilities available for use by these craft.

Commercial vessels include all sizes and types of boats, both military and civilian, from small fishing vessels to the largest supertankers. Three subcategories are considered, including:

Motorships,

Steamships, and

Others.

Motorships are powered by diesel engines and range in size from the smallest fishing boat to the largest freighters and tankers.

Steamships are powered by steam turbines. Steam is generated in boilers by burning any of several types of fuel. Coal is used in a few vessels while residual and distillate fuel oils are the dominant fuels used.

Emissions from commercial vessels are computed for "in port" operations (entering and leaving the port, docking and maneuvering) and power generation while the vessel is dockside. The required data for emission calculation include the number of vessels by type entering and leaving the port, and the average number of days that the vessel remains in port. Chapter 7 of this document details inventory and emission calculation procedures for this mobile source category.

2.2 INVENTORY PLANNING

Before any efforts are expended by personnel to collect the data inputs necessary to complete an emission inventory by the methods in this document, it is essential that the entire inventory effort be thoroughly planned. The planning and management aspects of emission inventory preparation are presented in Volume I of this series.[3] Additional instructions on inventory planning are contained in References 4 and 5.

References for Chapter 2.0

1. Procedures for Emission Inventory Preparation--Volume II: Point Sources, EPA-450/4-81-026b, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

2. Procedures for Emission Inventory Preparation--Volume III: Area Sources, EPA-450/4-81-026c, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

3. Procedures for Emission Inventory Preparation--Volume I: Emission Inventory Fundamentals, EPA-450/4-81-026a, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1981.

4. Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds--Volume I (Second Edition), EPA-450/2-77-028, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1980.

5. Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds--Volume II: Emission Inventory Requirements for Photochemical Air Quality Simulation Models, EPA-450/4-79-018, Office of Air Quality Planing and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

3.0 EMISSIONS FROM OFF-HIGHWAY SOURCES

Off-highway sources include motorized equipment and vehicles that normally are not operated on public highways to provide transportation service. There are six categories of off-highway sources. They are:

Farm equipment,

Construction equipment,

Industrial machinery,

Motorcycles,

Lawn and garden equipment, and

Snowmobiles.

A problem inherent in preparing inventories of off-highway source emissions is the lack of definitive data from which estimates of source activity can be made. Generally, records are maintained at the state level of motor fuel used by exempt vehicles, which means any vehicle (actually, any vehicle or piece of equipment or machinery) for which fuel taxes do not apply. Included are all types of vehicles, equipment, and machinery included in the off-highway emissions source category, as well as many public use vehicles (vehicles owned by state or local government agencies, etc.). Also, reimbursements for fuel used by vehicles involved in interstate commerce are also reflected in the figures for nontaxed fuel sales. Most state agencies responsible for maintaining this information aggregate it so that there is no way to separate the quantities of fuel used by individual categories of exempt users, such as construction and agricultural applications.

An additional problem in terms of data concerns the fact that there is very little information available regarding either the population of vehicles, machinery or equipment, or the utilization of individual types of vehicles and equipment contained in the off-highway category. As a result, the methods available to develop inventories of emissions from these sources rely extensively on assumptions and general application of a very limited amount of empirical data.

This section presents methods for deriving an inventory of emissions produced by sources within the off-highway vehicle category. Each of the six source categories is presented separately.

3.1 INVENTORYING EMISSIONS FROM FARM EQUIPMENT

The two types of sources within the farm equipment category are tractors and all other motorized equipment. Tractors account for most of the emissions produced from farm equipment. The primary types of equipment other than tractors are combines, balers, harvesters, and general purpose machines. Of interest in terms of emissions is the distribution of gasoline and diesel equipment within each equipment category.

Data are available from the U.S. Department of Commerce, Bureau of the Census, concerning the number of tractors and other specific types of farm equipment in each county in the U.S. and the typical utilization rates associated with each item of equipment. This information is reported in a document entitled Census of Agriculture,[1] which is published every 4 years.

The method presented here for inventorying emissions from farm equipment derives an activity factor that identifies the quantity of fuel used by each type of equipment during the inventory year and applies an emission factor that defines the quantity of each type of pollutant produced per gallon (or liter) of fuel burned.

Table 3-1 lists the data elements needed for the method described in this section. Sources of these data are also included in the table. However, should an agency have a different source that can supply the same data, that alternative source could be used.

TABLE 3-1. DATA REQUIREMENTS FOR CALCULATION OF EMISSIONS FROM FARM EQUIPMENT

Description	Units	Source	Identifier
Equipment population	Number of each type of equipment	Census of Agriculture[1]	N
Acres cultivated	Acres	State or County Agricultural Extension Service	ACR
Fuel usage by equipment type	Gallons/year per piece of equipment	U.S. EPA documents[2]	R
Pollutant emission factors	Pounds/1000 gallons of fuel	Table 3.2.6-2, AP-42[3]	EF

3.1.1 DERIVATION OF AN ACTIVITY FACTOR

The basic activity factor used to estimate emissions from farm equipment is the quantity of fuel burned by tractors and other motorized equipment during the inventory year. Separate estimates are required for diesel and gasoline use by each type of equipment.

Statistics concerning the county populations of various agricultural equipment items are available in Census of Agriculture.[1] These statistics include the number of tractors and other major items of equipment on farms in each county in the U.S. However, the population statistics alone do not provide an indication of the relative agricultural activity from year to year; therefore, a procedure that will provide this information is required.

The number of acres cultivated are used to indicate agricultural activity. These data are available from county or state agricultural extension services. It is necessary that the farm equipment population figures and the acres cultivated figures be for the same year.

Finally, the average annual quantity of fuel used per individual piece of farm equipment is required. These data are available from References 2 and 4, and are presented here as Table 3-2.

TABLE 3-2. AVERAGE ANNUAL FUEL THROUGHPUT FOR AGRICULTURAL EQUIPMENT

	Average annual fuel use (gallons per year)	
Equipment item	Gasoline	Diesel fuel
Combines	166	107
Balers	56	36
Harvesters	281	180
General purpose machines	176	97
Tractors	663	1460

The data presented in Table 3-2 and the study area farm equipment population determined from Census of Agriculture[1] are used to calculate an estimate of fuel used by farm equipment during the base year represented by the equipment census data. These fuel use estimates for the five equipment items shown in Table 3-2 are:

$$Q_d = \sum_{i=1}^{5} (N_{id} \times R_{id}) \qquad (3\text{-}1)$$

and

$$Q_g = \sum_{i=1}^{5} (N_{ig} \times R_{ig}) \qquad (3\text{-}2)$$

where Q_d = total annual quantity of diesel fuel used, in gallons, by all equipment types during the base year;

N_{id} = number of item i equipment in the study area that are diesel powered;

R_{id} = annual diesel fuel use rate, in gallons per year, for equipment type i, from Table 3-2;

Q_g = total annual gasoline use, in gallons, by all equipment types during the base year;

N_{ig} = number of item i equipment in the study area that are gasoline powered;

R_{ig} = annual gasoline use rate, in gallons per year, for equipment type i, from Table 3-2.

The total base year fuel quantities are then used together with the data on acreage of cultivated land to derive a factor describing the fuel use per acre cultivated:

$$f_b = [(1.4)(Q_d) + (Q_g)] / ACR_b \qquad (3\text{-}3)$$

where f_b = fuel use per cultivated acre factor for base year b;

Q_d = total diesel fuel used, in gallons, during base year b, from Equation (3-1); and

Q_g = total gasoline used, in gallons, during base year b, from Equation (3-2);

ACR_b = total acres cultivated in the study area during base year b.

In Equation (3-3), the quantity of diesel fuel, Q_d, is increased by a factor of 1.4 to normalize the quantities of diesel and gasoline on an equivalent energy basis. This equation is then transformed to:

$$[(1.4)(Q_d) + (Q_g)]_y = (f_b) \times ACR_y \qquad (3\text{-}4)$$

where $[(1.4)(Q_d) + (Q_g)]_y$ = the absolute value of the combined quantities of diesel and gasoline fuel used during inventory year y;

f_b = fuel use per cultivated acre factor derived for base year b, in Equation (3-3); and

ACR_y = total acres cultivated in the study area during inventory year y.

The individual quantities Q_d and Q_g can be determined by assuming that the proportion of gasoline to diesel use during the inventory year is the same as for base year b. Alternatively, if data indicate that some shift in the relative use of the two fuels has occurred between the base year and the inventory year, the new ratio can be substituted and the quantities Q_d and Q_g found algebraically. If estimates of future year values for ACR are available, estimates of fuel use can be derived, which will serve as the basis for deriving emission projections.

3.1.2 CALCULATION OF EMISSIONS

Once fuel use estimates have been calculated, emissions can be estimated using a set of emission factors defined in terms of emission quantity produced per gallon of fuel burned. These emission factors are in the U.S. Environmental Protection Agency's (EPA) Compilation of Air Pollutant Emission Factors,[3] (referred to hereafter as AP-42), in Table 3.2.6-2. The emission factors presented in AP-42 are for four groups of farm equipment:

Diesel tractors,

Gasoline tractors,

Other diesel farm equipment, and

Other gasoline farm equipment.

Because the emission factors only differentiate between farm tractors and other farm equipment, the activity factors (annual fuel use) calculated in Section 3.1.1 for combines, balers, harvesters, and general purpose farm equipment categories must be aggregated. The fuel usage must then be apportioned to the above four categories. The apportioning is based on the data contained in Table 3-2 and the equipment population data. Specifically:

$$f_{trad} = [(1460)(N_{trad})] \,/\, \sum_{i=1}^{5} [(R_{id})(N_{id})] \qquad (3\text{-}5)$$

$$f_{othd} = 1.00 - f_{trad} \qquad (3\text{-}6)$$

$$f_{trag} = [(663)(N_{trag})] \,/\, \sum_{i=1}^{5} [(R_{ig})(N_{ig})] \qquad (3\text{-}7)$$

$$f_{othg} = 1.00 - f_{trag} \qquad (3\text{-}8)$$

where f_{trad} = proportioning factor for diesel tractors;

N_{trad} = number of diesel tractors in the population;

R_{id} = fuel use rate, in gallons per year, for diesel equipment type i, from Table 3-2;

N_{id} = number of diesel farm equipment of type i in this population;

f_{othd} = proportioning factor for other diesel-powered farm equipment;

f_{trag} = proportioning factor for gasoline-powered tractors;

N_{trag} = number of gasoline-powered tractors in the population;

R_{ig} = fuel use rate, in gallons per year, for gasoline-powered equipment type i, from Table 3-2;

N_{ig} = number of gasoline-powered farm equipment of type i in the population; and

f_{othg} = proportioning factor for other gasoline-powered farm equipment.

The quantities of fuel consumed by equipment in each of the four categories during the inventory year are now calculated from the total gasoline and diesel fuel figures and the proportioning factors. Specifically:

$$Q_{trady} = Q_{dy} \times f_{trad} \qquad (3\text{-}9)$$

$$Q_{othdy} = Q_{dy} \times f_{othd} \qquad (3\text{-}10)$$

$$Q_{tragy} = Q_{gy} \times f_{trag} \qquad (3\text{-}11)$$

$$Q_{othgy} = Q_{gy} \times f_{othg} \qquad (3\text{-}12)$$

where Q_{trady} = quantity of diesel fuel used, in gallons, during inventory year y, by diesel tractors;

Q_{dy} = quantity of diesel fuel, in gallons, used by farm equipment during inventory year y;

f_{trad} = proportioning factor, from Equation (3-5);

Q_{othdy} = quantity of diesel fuel, in gallons, used by other types of farm equipment during inventory year y;

f_{othd} = proportioning factor from Equation (3-6);

Q_{tragy} = quantity of gasoline, in gallons, used by tractors during inventory year y;

Q_{gy} = total quantity of gasoline, in gallons, used by farm equipment during inventory year y;

f_{trag} = proportioning factor from Equation (3-7);

Q_{othgy} = quantity of gasoline in gallons, used by other types of farm equipment during inventory year y; and

f_{othg} = proportioning factor from Equation (3-8).

The solution of Equations (3-9) through (3-12) provides the annual fuel usage, during the inventory year, of farm tractors (diesel and gasoline) and other farm equipment (diesel and gasoline). The annual emissions (E) are now calculated by multiplying the annual fuel usages (Q) by the emission factors (EF) for each pollutant and equipment type from Table 3.2.6-2 of AP-42,[3] according to the following equations:

$$E_{trady,j} = Q_{trady} \times EF_{trad,j} \tag{3-13}$$

$$E_{othdy,j} = Q_{othdy} \times EF_{othd,j} \tag{3-14}$$

$$E_{tragy,j} = Q_{tragy} \times EF_{trag,j} \tag{3-15}$$

$$E_{othgy,j} = Q_{othgy} \times EF_{othg,j} \tag{3-16}$$

where $E_{trady,j}$ = total emissions of pollutant j, in pounds (kilograms) per year, from diesel-powered farm tractors in inventory year y;

Q_{trady} = quantity of diesel fuel used, in thousands of gallons, during inventory year y, by diesel farm tractors, from Equation (3-9);

$EF_{trad,j}$ = emission factors, in pounds (kilograms) of pollutant j per thousand gallons of diesel fuel used by farm tractors;

$E_{othdy,j}$ = total emissions of pollutant j, in pounds (kilograms) per year, from other diesel-powered farm equipment in inventory year y;

Q_{othdy} = quantity of diesel fuel used, in thousands of gallons, during inventory year y, by other diesel farm equipment, from Equation (3-10);

$EF_{othd,j}$ = emission factors, in pounds (kilograms) of pollutant j per thousand gallons of diesel fuel used by other farm equipment;

$E_{tragy,j}$ = total emissions of pollutant j, in pounds (kilograms) per year, from gasoline-powered farm tractors in inventory year y;

Q_{tragy} = quantity of gasoline used, in thousands of gallons, during inventory year y, by gasoline farm tractors, from Equation (3-11);

$EF_{trag,j}$ = emission factors, in pounds (kilograms) of pollutant j per thousand gallons of gasoline used by farm tractors;

$E_{othgy,j}$ = total emissions of pollutant j, in pounds (kilograms) per year, from other gasoline-powered farm equipment in inventory year y;

Q_{othgy} = quantity of gasoline used, in thousands of gallons, during inventory year y, by other gasoline farm equipment, from Equation (3-12); and

$EF_{othg,j}$ = emission factors, in pounds (kilograms) of pollutant j per thousand gallons of gasoline used by other farm equipment.

3.1.3 TEMPORAL RESOLUTION

The preceeding calculations estimated the total emissions from farm equipment for an entire year. It will frequently be necessary to determine what fraction of the yearly emissions are actually emitted on a seasonal basis, a daily basis, or an hourly basis. The amount of resolution (seasonal, daily, hourly) should be decided before the data gathering is initiated.

Agricultural activity has very pronounced seasonal variations. Peaks occur during planting and harvesting with moderate activity occurring during interim periods. Planting activity may be concentrated during the daylight hours while harvesting may be an around-the-clock activity. The majority of activity could be expected to occur Monday through Saturday with minimal activity on Sunday.

The precise variations in activity are difficult to quantify. However, agricultural extension service and farm bureau personnel will be able to supply information relative to when crops are planted and harvested and the length of time these activities require. Discussions with these agencies' personnel will supply sufficient information for a quantification of the distribution of activity.

Temporal resolution factors are expressed as percentages of yearly activity or emissions. When the temporal resolution factors are multiplied by the annual emissions, the quantity of annual emissions that occur seasonally, daily, or hourly are obtained. It is assumed that activity is directly proportional to emissions. The method for calculating temporal factors when information is obtained from extension service or farm bureau personnel is based on methods and assumptions available in the literature.[4,5]

Temporal allocation of annual emissions is often conducted prior to a modeling study. The actual data elements from the procedure that would be used by an analyst will depend on the purpose of the temporal resolution. Information on the computerization of temporal allocation factors can be found in The Airshed Model Data Handling System User's Guide.[6]

3.1.4 INVENTORY MAINTENANCE

The data required to update an inventory of farm equipment emissions are listed in Table 3-1. The calculations necessary are those presented previously in subsections 3.1.1 and 3.1.2.

Data on the number of cultivated acres are updated annually by agricultural extension services. They should be contacted to determine the latest year for which data are available. Census of Agriculture[1] data are updated every 4 years (1978 data were published in 1981). The emission factors in AP-42[3] are updated periodically as new data become available. The Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, or the U.S. Environmental Protection Agency Library at Research Triangle Park, NC, can be contacted to insure that the emission factors being used are the most current available.

As with all source categories, the analyst should properly document all data methods and assumptions used, as well as the results of the inventory. Reporting format and documentation should reflect the requirements specified in either state or Federal guidance documents. Additional instruction on reporting formats and documentation are included in Volume I of this series.[7]

3.2 INVENTORYING EMISSIONS FROM CONSTRUCTION EQUIPMENT

A wide variety of equipment is used in the construction industry. There is no standard classification system by which construction equipment are described, although the general function of the equipment and the available horsepower are parameters used in classification structures. General functional categories include bulldozers, power shovels, scrapers, haulers, and motor graders. Other, more descriptive categories, such as tracked bulldozers, wheeled dozers, and tracked power shovels can also be used.

With regard to inventorying emissions produced by construction equipment, a primary factor involved relates to the annual hours of use of this equipment during the inventory year. The hours of use statistic provides a basis for deriving the activity factor, which, once determined, is applied to an emission factor to yield emissions. The specific methodology is presented in this section.

3.2.1 DERIVATION OF AN ACTIVITY FACTOR

The activity factor used to inventory emissions from construction equipment is the utilization, in horsepower-hours, of each piece of equipment during the inventory year. Since direct estimates of equipment use for the construction industry are not available, surrogate data must be used to derive the estimates.

The surrogate data consist of national statistics concerning the construction equipment (population by type and horsepower), and construction industry employment statistics for both the state and nationwide. National population data have been developed for various categories of equipment, as shown in Table 3-3.

TABLE 3-3. NATIONAL CONSTRUCTION EQUIPMENT DATA

Type of equipment	Population	Average horsepower	Usage (hr/yr)
Tracklaying tractors	197,000	120	1050
Tracklaying loaders	86,000	65	1100
Motor graders	95,300	90	830
Scrapers	27,000	475	2000
Off-highway trucks	20,800	400	2000
Wheel loaders	134,000	130	1140
Wheel tractors	437,000	75	740
Rollers	81,600	75	740
Wheel dozers	2,700	300	2000
Miscellaneous	100,000	40	1200

Source: References 8 and 9.

These equipment populations are distributed to the study area on the basis of employment and population. Specifically, the state and national employment statistics for heavy construction [Standard Industrial Classification (SIC) 16] are determined from References 10 and 11. Population data are required for both the state and the study area. This information is available from a variety of sources at both the state and county level; for example, in planning and economic development offices, department of labor statistics (state), etc. The entire data set is then used to estimate the total number of each type of equipment listed in Table 3-3 used in the study area, from:

$$N_{ci} = (N_{ni}) \times (E_{cons} / E_{conn}) \times (POP_c / POP_s) \qquad (3\text{-}17)$$

where N_{ci} = number of pieces of equipment type i used in the county;

N_{ni} = number of pieces of equipment of type i in the national inventory, from Table 3-3;

E_{cons} = employment in construction, SIC 16, statewide;

E_{conn} = employment in construction, SIC 16, nationally;

POP_c = county population; and

POP_s = state population.

Data presented in Reference 8 concerning average horsepower, usage, and load cycle are multiplied together to develop an estimate of the annual work output, in horsepower-hours, for each piece of equipment in the various categories. These work output estimates are shown in Table 3-4.

TABLE 3-4. ANNUAL WORK OUTPUT ESTIMATES BY TYPE OF EQUIPMENT

Type of equipment	Annual work output (hp-hr)
Tracklaying tractors	84,400
Tracklaying loaders	21,400
Motor graders	22,400
Scrapers	617,500
Off-highway trucks	480,000
Wheel loaders	96,300
Wheel tractors	27,700
Rollers	16,600
Wheel dozers	390,000
Miscellaneous	14,400

Source: GCA calculations.

The data from Table 3-4 and the results of Equation (3-17) are used to derive an estimate of horsepower-hours of utilization for each type of equipment from:

$$HPRS_i = N_{ci} \times AWO_i \qquad (3\text{-}18)$$

where $HPRS_i$ = horsepower-hours of utilization of type i equipment;

N_{ci} = number of pieces of equipment type i used in the county, from Equation (3-17); and

AWO_i = annual work output, in horsepower-hours, for each piece of type i equipment, from Table 3-4.

3.2.2 CALCULATION OF EMISSIONS

Emissions are computed using the total annual work output for each type of equipment estimated in Equation (3-18) and applying an emission factor from AP-42.[3] Prior to calculating emissions, however, the $HPRS_i$ values must be apportioned by fuel type. Data contained in Reference 8 provide the basis for this apportionment, as shown in Table 3-5.

TABLE 3-5. DISTRIBUTION OF DIESEL-POWERED AND GASOLINE-POWERED CONSTRUCTION EQUIPMENT BY GENERAL TYPE

Type of equipment	Percent diesel	Percent gasoline
Tracklaying tractors	100	-
Tracklaying loaders	100	-
Motor graders	92.4	7.6
Scrapers	100	-
Off-highway trucks	100	-
Wheel loaders	70.0	30.0
Wheel tractors	84.6	15.4
Rollers	30.8	69.2
Wheel dozers	100	-
Miscellaneous	75.0	25.0

Source: Reference 8.

The percentages of diesel-powered and gasoline-powered equipment are applied to $HPRS_i$ to obtain horsepower-hours by type of equipment and by fuel type used. These data are used with emission factors, specified in terms of grams of pollutant per horsepower-hour, from Tables 3.2.7-1 and 3.2.7-2, in AP-42.[3] Emission estimates for each type of diesel-powered and gasoline-powered equipment are calculated from:

$$E_{di,j} = HPRS_i \times D_{di} \times EF_{di,j} \quad (3\text{-}19)$$

$$E_{gi,j} = HPRS_i \times D_{gi} \times EF_{gi,j} \quad (3\text{-}20)$$

where $E_{di,j}$ = annual emissions, in grams, of pollutant j from all diesel-powered equipment type i in study area;

$HPRS_i$ = horsepower-hours of utilization of type i equipment, from Equation (3-18);

D_{di} = percent of equipment type i that is diesel powered, from Table 3-5;

$EF_{di,j}$ = emission factor for pollutant j, in grams per horsepower-hour, from diesel-powered equipment type i, from Table 3.2.7-1 of AP-42;[3]

$E_{gi,j}$ = annual emissions, in grams, of pollutant j from all gasoline- powered equipment type i in study area;

D_{gi} = percent of equipment type i that is gasoline powered, from Table 3-5; and

$EF_{gi,j}$ = emission factor for pollutant j, in grams per horsepower-hour, from gasoline-powered equipment type i, from Table 3.2.7-2 of AP-42.[3]

3.2.3 INVENTORY MAINTENANCE

The methodology presented in this section is based heavily on data developed for a report published in 1973.[8] That report developed its data from a large number of different references. Information available, both then and now, on specific construction equipment population data, horsepower, usage or load factors is very limited. The method employed to estimate values for these factors in the 1973 report is lengthy.[8] Unless an agency can readily locate more current data of this type, specific for the area under its jurisdiction, the data presented here can be used.

The data on national and county employment and population used in Equation (3-17) are updated periodically. The sources of these data should be contacted to insure that the most current figures are used in updating the emission inventory.[10,11]

AP-42[3] emission factors are also periodically updated. Consult subsection 3.1.4 of this chapter for a source of updated factors.

3.3 INVENTORYING EMISSIONS FROM INDUSTRIAL EQUIPMENT

Industrial equipment includes a variety of types and sizes of machinery. Examples of the types of equipment included in this category are forklifts, mobile refrigeration units, auxiliary engines for hydraulic pump service on garbage trucks and other large vehicles, generator and pump service for utilities, airports, and state maintenance organizations, logging, mining, quarrying, oil field operations, and portable well-drilling equipment.[8] The majority of these equipment types are found at companies operating in Standard Industrial Classification (SIC) major groups 10 through 14, 20 through 39, 50 and 51.

Very few data exist regarding specific types of equipment associated with different industries. In terms of developing emission inventories, an assumption is made that the equipment-type distribution inherent in the emission factor data developed by EPA is appropriate for the particular industries in the area being inventoried. The method used for inventorying emissions from industrial equipment involves deriving an estimate of the total utilization in horsepower-hours of industrial equipment during the inventory year, and applying an emission factor defined in terms of quantity of pollutant produced per gallon of fuel consumed. This is very similar to the method used for construction equipment.

3.3.1 DERIVATION OF AN ACTIVITY FACTOR

National statistics regarding the population of industrial equipment have been developed indicating the total number of heavy-duty diesel, heavy-duty gasoline, and light-duty gasoline engines used in industrial applications.[8,12] The average size of these three categories of engines tends to be around 125 horsepower for diesels, 78 horsepower for heavy-duty gasoline, and 4 horsepower for light-duty gasoline engines; and the duty cycle (the ratio of the power actually used divided by the power available) of these engines is, on the average, about 0.3.[8] With this information, values of annual work output for each of the three categories of engines have been produced. These values are shown in Table 3-6.

TABLE 3-6. ANNUAL WORK OUTPUT ESTIMATES BY TYPE OF ENGINE

Engine category	Annual work output (hp-hr)
Heavy-duty diesel	22,500
Heavy-duty gasoline	7,000
Light-duty gasoline	360

Source: Reference 8.

Engine population based on national statistics is shown in Table 3-7.

TABLE 3-7. 1974 NATIONAL INDUSTRIAL EQUIPMENT POPULATION ESTIMATES

Engine category	Estimated population
Heavy-duty diesel	417,000
Heavy-duty gasoline	990,000
Light-duty gasoline	2,105,400

Source: Reference 8.

National engine population data are then apportioned to the area being inventoried. This is done by applying employment statistics as shown in Equation (3-21). That equation indicates apportionment to a county by using county employment data. Apportionment to any other geographic or political area can be accomplished by applying employment data specific to that area instead of county data in Equation (3-21):

$$N_{ci} = (N_{ni}) \times (EMP_{indc} / EMP_{indn}) \quad (3\text{-}21)$$

where N_{ci} = number of type i engines in the county;

N_{ni} = number of type i engines nationally, from Table 3-6;

EMP_{indc} = county employment in industry, SIC codes 10-14, 20-39, and 50-51; and

EMP_{indn} = national employment in industry, SIC codes 10-14, 20-39, and 50-51.

Employment data required in Equation (3-21) are obtained from References 10 and 11. The activity factor, work output, is calculated as:

$$HPRS_i = N_{ci} \times AWO_i \quad (3\text{-}22)$$

where $HPRS_i$ = horsepower-hours of utilization of type i equipment;

N_{ci} = number of pieces of equipment type i used in the county, from Equation (3-21); and

AWO_i = annual work output, in horsepower-hours, for each piece of type i equipment, from Table 3-6.

3.3.2 CALCULATION OF EMISSIONS

Emissions are computed using the total annual work output, $HPRS_i$, for each type of industrial engine from Equation (3-22) and applying an emission factor from AP-42.[3] When calculating emissions, the $HPRS_i$ values for heavy-duty and light-duty gasoline engines must be summed because the emission factors in AP-42 do not differentiate between these engines. Emissions from diesel and gasoline industrial equipment are calculated from:

$$E_{d,j} = HPRS_d \times EF_{d,j} \tag{3-23}$$

$$E_{g,j} = (HPRS_{hg} + HPRS_{lg}) \times EF_{g,j} \tag{3-24}$$

where $E_{d,j}$ = annual emissions of pollutant j from diesel equipment, in grams;

$HPRS_d$ = horsepower-hours of utilization of diesel equipment, from Equation (3-22);

$EF_{d,j}$ = emission factor for pollutant j, in grams per horsepower-hour, from diesel equipment, from Table 3.3.3-1 of AP-42;[3]

$E_{g,j}$ = annual emissions of pollutant j from gasoline equipment, in grams;

$HPRS_{hg}$ = horsepower-hours of utilization of heavy-duty gasoline equipment, from Equation (3-22);

$HPRS_{lg}$ = horsepower-hours of utilization of light-duty gasoline equipment, from Equation (3-22); and

$EF_{g,j}$ = emission factor for pollutant j, in grams per horsepower-hour, from gasoline equipment, from Table 3.3.3-1 of AP-42.[3]

3.3.3 INVENTORY MAINTENANCE

The problems encountered and the data required in updating emissions from this category are identical to those for construction equipment. Refer to subsection 3.2.3 of this chapter for details.

3.4 INVENTORYING OFF-HIGHWAY MOTORCYCLE EMISSIONS

Off-highway motorcycles include trail bikes, minibikes, other motorized two- or three-wheeled recreational vehicles, and on-highway motorcycles when operated off-highway. These vehicles are minor contributors to air pollutant emissions. Estimates of emissions can be made using motorcycle registration statistics and AP-42[3] emission factors.

3.4.1 DERIVATION OF AN ACTIVITY FACTOR

The activity factor for off-highway motorcycle use is vehicle-miles-traveled (VMT). To derive an estimate of VMT by off-highway motorcycles, several assumptions are required. Since motorcycles used primarily for off-highway activity are not always registered, data may not exist on the population of these vehicles. The assumption used is that the total off-highway motorcycle VMT is a function of the total number of motorcycles registered for on-highway use. Specifically, this relationship is:

$$VMTMC_{offhwy,a} = MCREG_a \times 700 \text{ miles/year} \qquad (3\text{-}25)$$

where $VMTMC_{offhwy,a}$ = off-highway vehicle-miles traveled annually in area a, and

$MCREG_a$ = number of motorcycles registered in area a.

The usage factor of 700 miles per year in Equation (3-25) is from Reference 4.

Motorcycle registration data for the study area are obtained from the state motor vehicle registry. If county-specific data are not available, state level data can be apportioned based on population, as:

$$MCREG_a = (POP_a/POP_s) \times MCREG_s \qquad (3\text{-}26)$$

where $MCREG_a$ = number of motorcycles registered in area a,

POP_a = population of area a,

POP_s = population of the state, and

$MCREG_s$ = number of motorcycles registered statewide.

3.4.2 CALCULATION OF EMISSIONS

Emission factors for motorcycles are provided in AP-42, Table 3.1.7-1.[3] Separate factors are provided for 2-stroke and 4-stroke engines in grams per mile. Composite factors, based on the national distribution of 38 percent 2-stroke and 62 percent 4-stroke, are provided here in Table 3-8.

TABLE 3-8. COMPOSITE EMISSION FACTORS FOR MOTORCYCLES

Pollutant	Composite emission factors (g/mi)
Carbon monoxide	31
Hydrocarbons	
Exhaust	7.9
Crankcase	0.23
Evaporative	0.36
Nitrogen oxides	0.19
Particulates	0.154
Sulfur oxides	0.028
Aldehydes	0.071

Source: GCA calculations.

Emissions are computed as:

$$E_{mc,j} = EF_j \times VMTMC_{offhwy,a} \qquad (3\text{-}27)$$

where $E_{mc,j}$ = total annual emissions of pollutant j, in pounds (kilograms) per year, from off-highway motorcycle use;

EF_j = emission factor in pounds (kilograms) per mile, for pollutant j; and

$VMTMC_{offhwy,a}$ = off-highway vehicle-miles traveled annually in area a.

3.5 INVENTORYING LAWN AND GARDEN EQUIPMENT EMISSIONS

Included in this category are lawnmowers, lawn and garden tractors, tillers, edgers, and snowthrowers. These machines are minor contributors to air pollutant emissions. Emissions from lawn and garden equipment are calculated by apportioning national fuel use to the local level and applying emission factors from AP-42, Table 3.2.5-1.[3]

3.5.1 DERIVATION OF AN ACTIVITY FACTOR

The activity factor used for calculating emissions from lawn and garden equipment is the quantity of fuel used annually by this category. To do this, the statewide total off-highway fuel use data from the National Emissions Data System (NEDS) Fuel Use Report[13] are required. The national average of off-highway fuel used in lawn and garden equipment is 20 percent.[13,14] It is therefore assumed that 20 percent of the statewide use is used by these machines. Statewide fuel use is then apportioned to the county or planning area level on the basis of housing density, as follows:

$$Q_{LG,a} = (0.2) \times (Q_{SOH}) \times (SDU_a/SDU_s) \qquad (3\text{-}28)$$

where $Q_{LG,a}$ = quantity of fuel, in gallons, used by lawn and garden equipment in area a;

Q_{SOH} = quantity of fuel, in gallons, used for off-highway purposes in the state;

SDU_a = number of single dwelling units in area a, from Reference 15; and

SDU_s = number of single dwelling units in the state, also from Reference 15.

3.5.2 CALCULATION OF EMISSIONS

The quantity of fuel used by lawn and garden equipment is used with an emission factor from Table 3.2.5-1 of AP-42[3] to calculate emissions. This table lists separate emission rates for 2-cycle and 4-cycle engines. National data[12] indicate that 93 percent of small engines used for lawn and garden equipment are 4-cycle. This distribution can be applied directly to the fuel use derived in Equation (3-28) to estimate the quantity of fuel used by 4-cycle lawn and garden equipment. The remainder of the total fuel is assumed to be used by 2-cycle equipment.

Emissions are computed as:

$$E_{LG,aj} = (0.93) \times (Q_{LG,a}) \times (EF_{4,j}) + (0.07) \times (Q_{LG,a}) \times (EF_{2,j}) \qquad (3\text{-}29)$$

where $E_{LG,aj}$ = total emissions, in pounds (kilograms) of pollutant j produced by lawn and garden equipment in area a;

$Q_{LG,a}$ = quantity of fuel, in gallons, used by lawn and garden equipment in area a, from Equation (3-28);

$EF_{4,j}$ = emission factor, in pounds (kilograms) of pollutant j per gallon of fuel burned, for 4-cycle lawn and garden equipment, from Table 3.2.5-1 of AP-42;[3] and

$EF_{2,j}$ = emission factor, in pounds (kilograms) of pollutant j per gallon of fuel burned, for 2-cycle lawn and garden equipment, from Table 3.2.5-1 of AP-42.[3]

3.6 INVENTORYING EMISSIONS FROM SNOWMOBILES

Snowmobiles are a relatively minor source of emissions and are of concern in areas such as the northeast and northern midwest portions of the U.S. These areas account for almost 90 percent of the snowmobile use in the U.S.[3]

3.6.1 DERIVATION OF AN ACTIVITY FACTOR

The activity factor for snowmobiles is the number of individual snowmobiles in use in the study area. Factors concerning the average number of hours of use per snowmobile, the hourly fuel consumption rate, and the emissions characteristics were used by EPA to derive a set of emission factors based on emissions per snowmobile.

The activity factor, that is, the study area snowmobile population, is obtained from the state agency responsible for maintaining registration statistics. If county-specific registration data are not available, statewide data can be apportioned from:

$$SNBLRG_a = (SNBLRG_s) \times (RURPOP_a/RURPOP_s) \quad (3\text{-}30)$$

where $SNBLRG_a$ = snowmobile population for area a;

$SNBLRG_s$ = statewide snowmobile population from registration data;

$RURPOP_a$ = rural population of area a, from Reference 16; and

$RURPOP_s$ = rural population of the state, from Reference 16.

3.6.2 CALCULATION OF EMISSIONS

Emissions from snowmobiles are estimated using annual per-unit emission factors found in AP-42, Table 3.2.8-1.[3] These factors are based on an average of 60 hours of operation per year and fuel consumption of 0.94 gal/hr.[17] Emissions are calculated as:

$$E_{snbl,aj} = (EF_j) \times (SNBLRG_a) \qquad (3\text{-}31)$$

where $E_{snbl,aj}$ = total emissions of pollutant j, in pounds (kilograms) per year, produced by snowmobiles in area a;

EF_j = emission factors, in pounds (kilograms) of pollutant j per year per snowmobile; and

$SNBLRG_a$ = snowmobile population in area a, from Equation (3-30).

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4.0 EMISSIONS FROM HIGHWAY VEHICLES

In most urban areas, highway vehicles represent the largest single source of carbon monoxide (CO) emissions and contribute significantly to the area's total production of hydrocarbons (HC), sulfur oxides (SO_x), and oxides of nitrogen (NO_x). The purposes of this section are to identify the relationships that exist between mobile source activity and emission production, and to present four methods for inventorying emissions from highway vehicles.

The process of developing an inventory of emissions from highway vehicles is complex, regardless of the method used. State, regional, and county transportation engineering and planning agencies must be involved. The data available from these agencies and the expertise of their personnel are required in the methods used to inventory emissions from highway vehicles.

4.1 GENERAL CONSIDERATIONS

The quantity of emissions produced regionally from motor vehicles is a function of the amount of travel--that is, vehicle-miles of travel (VMT)--that occurs, of specific characteristics of the vehicles performing the travel, travel parameters, and of certain environmental factors. The emission inventory process must account for these factors whether explicitly as part of the source characterization, or implicitly in the selection of emission factors.

The most fundamental relationship between emissions and highway vehicles as a source concerns the amount of travel that occurs within a particular area. However, since emissions are also affected by specific characteristics of the vehicle population and the environment, regional travel estimates must be defined in terms of VMT by various types of vehicles operating in each of several types of environmental settings.

Vehicle characteristics that are of interest include those that relate to the vehicle itself, and to the operation of the vehicle. In terms of the individual vehicle, emissions are affected by:

The type, size, and configuration of the engine;

The types of emission control devices used;

The general condition of the engine; and

The type of vehicle.

Two types of engines are currently used for highway vehicles--gasoline engines (Otto cycle), and diesel engines. Each displays unique emission characteristics; therefore, it is necessary to determine the relative distribution of gasoline-powered and diesel-powered vehicle travel in the emission inventorying procedure. Engine size (displacement) and configuration (block type, number of cylinders, special characteristics of the combustion area design or type of fuel delivery system, etc.) also affect emission characteristics of the individual vehicle. However, these are reflected in the emission factors, which represent a composite of all engine sizes and configurations for a particular model year, and therefore are not explicitly considered in deriving an emission inventory.

Beginning with the 1968 model-year, vehicles manufactured in or imported into the U.S. have had to meet emission standards that have become increasingly stringent over time. As more stringent standards have come into effect, the control technology applied to various model-year vehicles changed as well. In terms of emission control technology, the particular model year reflects both the general technology applied, and a specific level of overall emission control. In the inventorying process, then, the distribution of VMT by model year is required.

Regardless of the type of emission control technology applied, a certain amount of deterioration can be expected in the effectiveness of the emission controls as the vehicle accumulates mileage. Emission factors for motor vehicles reflect this deterioration by assigning a higher emission rate to a particular model year as the vehicle age represented by that model year increases.* Again, the vehicle age distribution is required as part of developing emission estimates.

The type of vehicle refers to eight categories, including:

Light-duty, gasoline-powered vehicles (LDGV), i.e., passenger cars;

Light-duty, diesel-powered vehicles (LDDV);

Light-duty, gasoline-powered trucks, type 1 (LDGT1), i.e., pickup trucks and vans that have a gross vehicle weight (GVW) less than 6000 pounds;

Light-duty, gasoline-powered trucks, type 2 (LDGT2), i.e., pickup trucks, vans, and other small trucks that have a GVW between 6000 and 8500 pounds;

Light-duty, diesel-powered trucks (LDDT);

Heavy-duty, gasoline-powered vehicles (HDGV), i.e., all vehicles with a GVW greater than 8500 pounds, powered by gasoline engines;

Heavy-duty, diesel powered vehicles (HDDV), i.e., essentially all diesel-powered trucks; and

Motorcycles (MC).

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*Mileage accumulation and vehicle age correlate very well.

Large differences exist in the emission characteristics of vehicles represented by these categories, therefore, regional travel estimates must reflect the distribution of VMT by vehicle type.

In addition to being sensitive to the vehicles' physical characteristics, emissions are also affected by the operating mode. Instantaneous emission rates are very different for cruise, acceleration, deceleration, and idle modes. The amount of detailed data required to perform a modal analysis precludes using this approach for areawide inventories. The more usual procedure is to consider travel in the context of the whole trip, whereby a modal distribution is assumed and the average vehicle speed is used.

Another operational parameter that affects the emission characteristics of most vehicles is the amount of travel that occurs while the vehicle is in (1) the cold transient mode, (2) the hot stabilized mode, and (3) the hot transient mode.* These modes reflect the impact of engine operating temperature on the emission characteristics of gasoline powered vehicles. The CO and HC emission rates for these vehicles are much higher during the first few minutes of operation when the choke is closed and various engine components (including the catalytic converter) have not yet reached their normal operating temperatures. This transition period from a cold (ambient) to stabilized operating temperature is referred to as the cold-start mode. The time required for an engine and its related systems to reach a stabilized operating temperature depends on several factors, such as the amount of time that the engine was not run (cold soaked) prior to starting, mass of the engine, ambient temperature, and others. In actuality, the time required for an engine to reach the stabilized mode is a function of the initial starting temperature and the thermodynamic properties of the engine, which represents a fairly complex relationship. For emission estimation purposes, however, the relationship is treated as a simple, discrete function. Specifically, the cold-start mode is defined as the first 505 seconds of operation after the vehicle has cold soaked for at least 1 hour, if equipped with a catalytic converter, or 4 hours if a converter is not used. Vehicles that are restarted after a relatively short soak period (less than 1 hour for vehicles equipped with a catalytic converter or less that 4 hours for noncatalyst vehicles) are considered to be operating in the hot-start mode.

Travel parameters used in the inventory must account for differences in the emission rates associated with cold-start, hot-start, and stabilized operating modes. This is accomplished through the analysis of the region's travel characteristics, or, for less detailed inventories, by applying assumed values. Details regarding these two methods and their applications are presented in subsequent paragraphs.

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*These three modes are referred to here as cold-start, stabilized, and hot-start, respectively.

Several other, less important factors relating to vehicle operation exist. These concern the impact of additional engine loading on emissions. Specifically, emission rates tend to increase when a vehicle is towing a trailer, carrying an abnormally heavy load, or when its air conditioner is being used. Although the impact of the additional engine loading on emission rates is quite small, it can be accounted for where the overall inventory is to be sufficiently detailed to warrant the extra effort involved. Information needed to apply these factors, however, is usually difficult to obtain.

Motor vehicle emission rates are sensitive to several environmental factors. The two most important ones are ambient temperatures and altitude. Ambient temperature has a pronounced impact on cold mode emissions. Colder temperatures result in lower overall combustion efficiency and require a much richer air-fuel mixture during initial warm up, both of which increase CO and HC emission rates. Emission rates generally increase with altitude since the lower density of the ambient air at high altitudes effectively creates a richer air-fuel mixture. For emission inventorying purposes, different emission rates are used depending on whether the area is located above or below 4000 feet elevation.

The above factors apply to tailpipe emissions, which result from the combustion of fuel. Several other sources of emissions are associated with motor vehicles, including evaporative and crankcase HC emissions, tire wear, and roadway dust entrainment. Evaporative losses result from the expansion and contraction of the air and fuel vapor mixture in the vehicle's partially filled gasoline tank, and from hot soak losses that occur from the carburetor areas after the engine has been shut down. Crankcase emissions occur when pressure builds up in the oil sump and lubricating oil vapor is vented. Both evaporative and crankcase emissions from newer vehicles are controlled as a result of the Federal Motor Vehicle Emissions Control Program (FMVECP).

Tire wear accounts for a relatively small fraction of the particulate emissions produced by mobile sources. The actual amount of wear, measured in terms of grams per mile, is related to many factors, such as tire design, wheel loading, vehicle speed, road surface abrasiveness, and the relative amount of braking that occurs. For emission inventory development, average wear rates are used to calculate emissions, in pounds or grams, per mile of travel.

Entrainment of particulate matter occurs as a result of air turbulence from moving vehicles acting on roadside deposits. The entrainment of particulate matter from roadways is associated with the fugitive emissions category and therefore not included as part of the mobile source inventory. Fugitive emission quantification procedures are presented in Volume III of this series.[1]

4.2 MOBILE SOURCE EMISSION FACTORS

Two sources are used to derive emission factors for highway vehicles. The first source is a computer program entitled MOBILE2,[2] which provides the capability of deriving CO, HC, and NO_x emission factors for all vehicle types and for a wide variety of environmental and operating conditions. The second source is a document entitled Compilation of Air Pollutant Emission Factors: Highway Mobile Sources,[3] which will be referred to hereafter as AP-42. AP-42 provides the capability of deriving SO_x and particulate emission factors for highway vehicles.

4.2.1 MOBILE2 EMISSION FACTOR MODEL

The MOBILE2 emission factor program provides an integrated set of FORTRAN routines for deriving motor vehicle emission factors that are sensitive to the composition of vehicles in the population, the operating characteristics of the vehicles, and the environmental conditions in which the vehicle fleet is operated. MOBILE2 is widely used currently, thus, even local air pollution agencies without direct access to computers are able to access the program through their state-level agency.

The emission factors produced by the MOBILE2 model are derived from the adjustment of a baseline composite emission factor, which reflects the standard set of conditions used in the Federal Test Procedure (FTP). The FTP involves the simulated operation of a vehicle over a specific driving cycle--the Urban Driving Cycle--under controlled operating and environmental conditions, during which emissions are measured in three sequences. The Urban Driving Cycle represents a 7.5 mile trip over an urban highway network that includes travel on local and arterial streets, and major arterials and expressways. The average speed over the 7.5 mile cycle is 19.6 miles per hour. In MOBILE2, if an input speed that is different from 19.6 miles per hour is defined, an emission factor will be computed for a different distribution of operating modes; if, for example, the input speed is higher, less idling and stop and go driving will be reflected. Many different combinations of driving modes can result in the same average speed, but totally different emission characteristics. In spite of the potential inaccuracy that may be introduced, use of the Federal Test Procedure represents the most practical method for deriving composite emission factors for highway vehicles.

MOBILE2 is based on emission data and procedures developed by EPA and reported in Mobile Source Emission Factors,[4] which supercedes portions of AP-42 concerning emissions of CO, HC, and NO_x from highway vehicles. In order to fully understand the process of deriving emission factors for highway vehicles, reference should be made to AP-42, the MOBILE2 User's Guide, and Mobile Source Emission Factors.[2,3,4]

In applying MOBILE2, the user specifies a number of parameters that reflect local characteristics in terms of the vehicle fleet, the highway network, and the environment, or he can elect to use default values that reflect national averages for some parameters. Specific parameters that are required as input to MOBILE2 include:

Region for which emission factors are to be calculated (i.e., low altitude, high altitude, or California);

Calendar year;

Vehicle speed;

Ambient temperature;

Percentage of total VMT attributable to noncatalyst vehicles operating in the cold-start mode;

Percentage of total VMT attributable to catalyst-equipped vehicles operating in the hot-start mode; and

Percentage of total VMT attributable to catalyst-equipped vehicles operating in the cold-start mode.

The user has a choice of specifying local data or using default values for the following:

Distribution of VMT by vehicle type;

Vehicle model year and accumulated mileage distributions;

Baseline emission rates; and

Factors to correct LDV emissions for air conditioner use, extra loading, trailer towing, and humidity.

MOBILE2 also accounts for the impact of motor vehicle inspection and maintenance (I/M) programs and is sensitive to such factors as the length of time that the program has been in effect, the stringency or failure rate, and the specific vehicles by type and model year affected by the program.

4.2.2 AP-42

The use of AP-42 in the emission inventorying process is quite simple since both particulates and sulfur oxides (SO_x) emissions are computed as a function of VMT by vehicle type, only. Emission factors for these two pollutants are provided for each vehicle type in the AP-42 document. The emission factor for SO_x is based on assumed sulfur content of the fuel, and average fuel consumption rate. If local conditions warrant different assumptions, an adjustment to the emission factors can be easily made.

4.3 OVERVIEW OF METHODS FOR COMPILING EMISSION ESTIMATES

Four methods for developing inventories of highway vehicle emissions are presented here. Their applicability and limitations are summarized in Table 4.1.

TABLE 4-1. SUMMARY OF USE AND LIMITATIONS OF HIGHWAY VEHICLE EMISSION CALCULATION METHODS

	Type of area for which method is appropriate		Appropriate uses of method				
Method	Rural & urban <50,000 pop.	Urban >50,000 pop.	Inventory of total areawide emissions	Assessment of impact of TCM's[a] on areawide emissions	Application of EKMA[b] Model to estimate control requirements	Application of ozone diffusion models to estimate control requirements	Comments
1. Apportion statewide travel data to smaller geographical areas	X		X				Useful only for producing gross estimate of areawide emissions
2. Use of FHWA[c]/EPA manual procedure		X	X		X		Quality of emission estimate is improved by using local sources of travel data, rather than synthetic approach in Reference 9
3. Link-based procedure		X	X	X	X		Not useful for evaluating TCM's[a] which mainly affect trip-related emissions
4. Hybrid procedure		X	X	X	X	X	Most data-intensive procedure, but most useful for SIP[d] development

[a] TCM = Transportation Control Measure

[b] EKMA = Empirical Kinetic Modeling Approach

[c] FHWA = Federal Highway Administration

[d] SIP = State Implementation Plan

The first method is intended for use in rural or small urban areas where local travel estimates are not available. This method derives local travel estimates and vehicle operation characteristics from statewide data and general characterizations of the highway vehicle source category. The method provides a general inventory of highway vehicle emissions. This method, while adequate for rural areas and urban areas with populations less than 50,000, should not be used for larger urban areas.

The second method presented here for developing a highway source emission inventory is, like the method outlined above, a process that is intended for use in instances where the emphasis is on expediency rather than precision. It is different from the first method, however, in that it requires significantly more local data and is primarily intended for use in urbanized areas. This method also accounts for more variables than the first method. It is intended to provide estimates of highway emissions as a function of travel-related emissions, trip-related emissions, and vehicle-related emissions, whereas the first method assumes that total emissions are a function of travel only (vehicle-related and trip-related emissions are not explicitly considered). The method was developed by the U.S. Department of Transportation, Federal Highway Administration (FHWA), and will be referred to here as the FHWA manual process.

The third and fourth methods are designed to integrate formal transportation planning and air quality planning efforts by utilizing transportaton planning data from urban area 3-C transportation planning processes as input to an emission model to yield emission estimates. The third method, referred to as the link-based approach, uses detailed information developed by the transportation planning process regarding the use and operational characteristics of individual segments (that is, links) of the region's highway system, and a single emission factor developed for the individual link, to estimate emissions. The fourth method, referred to as the hybrid approach, is similar to the link-based approach with the exception that travel-related, trip-related, and vehicle-related emission components are derived separately. This approach provides a high degree of spatial sensitivity to those factors that affect emissions; however, the method is more data intensive and requires a significantly greater investment compared to the link-based approach.

4.4 METHOD 1--ESTIMATING EMISSIONS FOR RURAL COUNTIES AND SMALL URBAN AREAS

Mobile source emissions are derived as a function of an activity factor--vehicle-miles of travel (VMT)--and an emission factor. For many rural and small urban areas very little data are likely to exist regarding the amount of vehicle travel that occurs. Further, given the high cost of developing VMT data through direct measurements, it is not likely that special studies would be performed to derive travel data for these areas. Notwithstanding the problem of limited or nonexistent data, it is often necessary to develop an inventory of emissions produced by vehicular traffic in these areas. The purpose of this section is to discuss methods that can be applied to derive an inventory of emissions from highway vehicles in rural or small urban areas where local tranportation data are limited.

The general process involves the apportionment of statewide VMT to the county (or other appropriate areas). Statewide VMT data are tabulated by all state transportation agencies and reported to the Federal Highway Administration (FHWA), which, in turn, publishes these and other similar data in Highway Statistics.[5] It should be noted that many states now have and others are developing the capability of reporting county level VMT. In states where this capability exists, the method described here for apportioning state level VMT data to the county level would not be applicable.

Central to this overall method is the development of apportioning factors, which, when applied to the statewide total, yield the countywide VMT. Several bases exists for apportioning VMT, such as fuel sales, population, motor vehicle registrations, and roadway mileage. The specific basis selected will depend on the availability of required data. Given the variability from state to state (and from county to county within a particular state) of the types of transportation-related statistics maintained, it is not possible to conclude in a general sense that one basis for developing an apportioning factor is better (that is, more accurate, easier to use, more cost effective to utilize, etc.) than any of the others. Selection of general methods should be made only after carefully and thoroughly researching the availability and quality of essential data. A key aspect of this process is to obtain the assistance of state and county transportation engineers and planners who should be able to provide the best assessment of both data availability and quality. The entire data assessment phase should be completed prior to selecting this method for conducting the inventory since the underlying assumption is that no direct estimates of county VMT are available.

Once the apportioning method has been developed, the resulting factors are applied to statewide VMT to produce estimates of countywide travel. Other data are applied to yield VMT by vehicle type and roadway classification. This represents the activity level for the county. The remainder of the process involves the derivation of additional data concerning county-specific environmental characteristics, and applying these and the VMT data as input to an emission model. Also, a common requirement among all methods and emission source categories is the management of the inventory data. This aspect of inventory development is discussed in a separate section. Figure 4-1 provides an overview of the inventory method and indicates the sections of this report where instructions can be found.

4.4.1 DATA ASSESSMENT

This is the first task undertaken after determining that there is a need for developing an inventory of emission from highway vehicles in a rural county or small urban area. The intent is to determine exactly what data are available, or could be derived directly from existing data, that are relevant to the development of the emission inventory. In order to accomplish this step, the analyst must be familiar with the basic concepts of emission inventory development, and have a sound understanding of factors that influence the emission characteristics of the highway system. In this regard

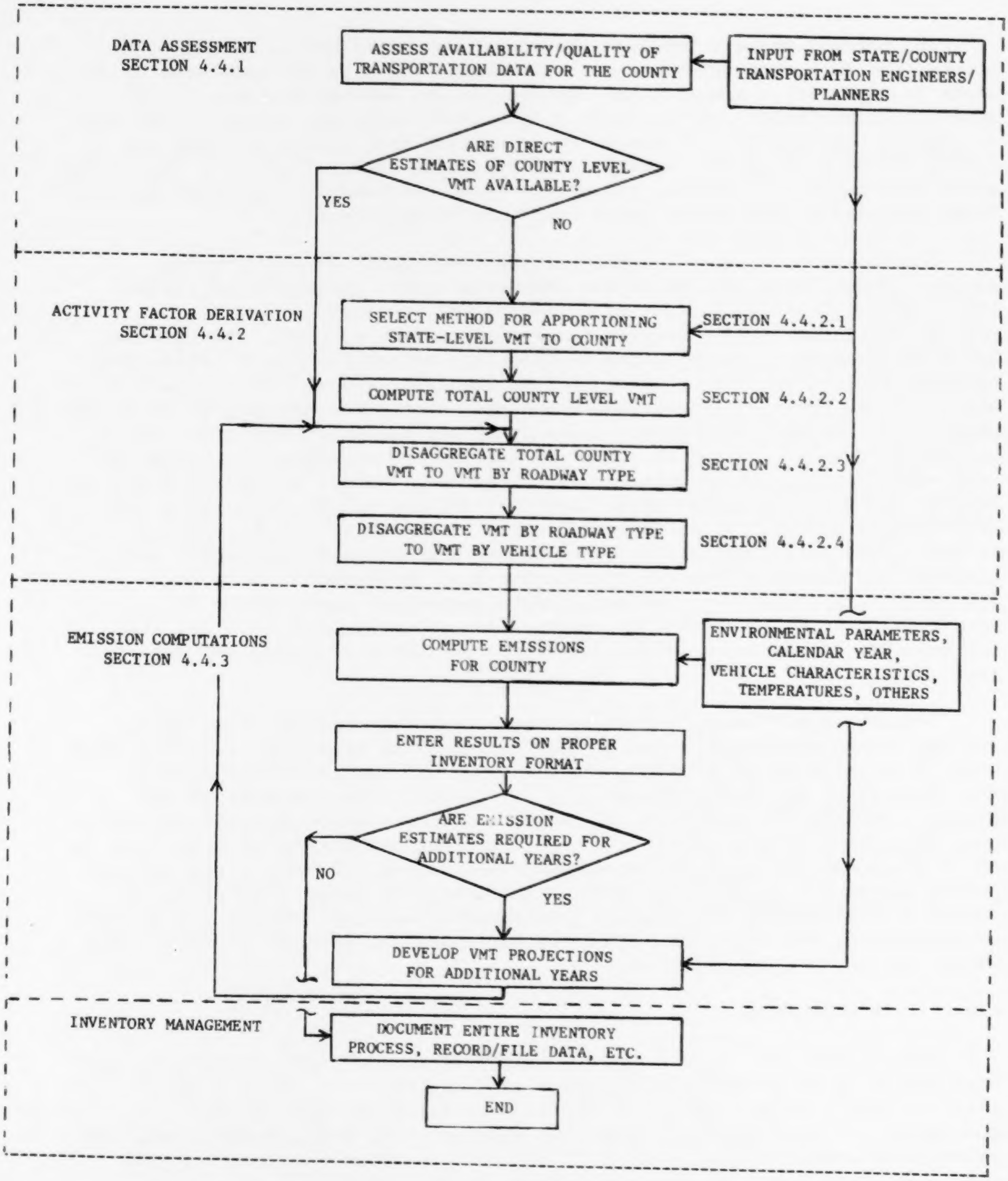
DATA ASSESSMENT
SECTION 4.4.1
ASSESS AVAILABILITY/QUALITY OF TRANSPORTATION DATA FOR THE COUNTY
INPUT FROM STATE/COUNTY TRANSPORTATION ENGINEERS/ PLANNERS
ARE DIRECT ESTIMATES OF COUNTY LEVEL VMT AVAILABLE?
YES
NO
ACTIVITY FACTOR DERIVATION
SECTION 4.4.2
SELECT METHOD FOR APPORTIONING STATE-LEVEL VMT TO COUNTY
SECTION 4.4.2.1
COMPUTE TOTAL COUNTY LEVEL VMT
SECTION 4.4.2.2
DISAGGREGATE TOTAL COUNTY VMT TO VMT BY ROADWAY TYPE
SECTION 4.4.2.3
DISAGGREGATE VMT BY ROADWAY TYPE TO VMT BY VEHICLE TYPE
SECTION 4.4.2.4
EMISSION COMPUTATIONS
SECTION 4.4.3
COMPUTE EMISSIONS FOR COUNTY
ENVIRONMENTAL PARAMETERS, CALENDAR YEAR, VEHICLE CHARACTERISTICS, TEMPERATURES, OTHERS
ENTER RESULTS ON PROPER INVENTORY FORMAT
ARE EMISSION ESTIMATES REQUIRED FOR ADDITIONAL YEARS?
NO
YES
DEVELOP VMT PROJECTIONS FOR ADDITIONAL YEARS
INVENTORY MANAGEMENT
DOCUMENT ENTIRE INVENTORY PROCESS, RECORD/FILE DATA, ETC.
END

Figure 4-1. General process for developing highway source emission estimates for rural counties or small urban areas.

it is appropriate that the MOBILE2 User's Guide[2] be reviewed prior to beginning this task.

The process of identifying and evaluating the necessary data should include input from state and county transportation engineers and planners. These individuals are most familar with both the data that are available and the data required as input to the emission model, therefore, their assistance should be solicited.

The first question to be answered during this phase is: Are direct estimates of county VMT available? If VMT estimates are available the problem becomes one of disaggregating it to a level that is suitable for input into an emission model. In this instance the concern becomes how to disaggregate the VMT data. If direct estimates of county level VMT are not available, the immediate concern is to develop a basis for disaggregating statewide VMT estimates obtained either from Highway Statistics[5] or the state transportation agency. During the process of answering the question concerning the availability of VMT data, the availability and quality of other pertinent data should be determined. The specific types of data that are of concern are discussed in the following paragraphs.

4.4.2 ACTIVITY FACTOR DERIVATION

The preceeding step establishes whether or not direct estimates of county VMT are available. If county estimates are not available, total statewide VMT estimates must be obtained, from which county estimates can be derived. Statewide VMT estimates are available directly from state transportation/highway agencies, and from Table VM-2 in Highway Statistics[5] (included here as Table 4-2). Four methods for apportioning these statewide totals to county or other subareas are presented below.

4.4.2.1 Apportionment of Statewide VMT

The first apportioning method is based on fuel sales data. An assumption inherent in this method is that VMT and fuel sales are directly related. In order for this method to be practical, county fuel sales data must be available. If it is determined that county fuel sales data are not available, one of the other three methods of allocating state VMT presented here should be considered.

Since all states collect taxes on motor fuel sold within their boundaries, formal records are maintained regarding both the fuel throughput and the revenue derived therefrom. These statistics are usually aggregated as state totals, therefore, special processing of the source data may be required to identify statistics for a particular county. The data requirements should be discussed with appropriate officials in the state taxation or revenue agency.

As a minimum, total annual sales (gallons) of gasoline and diesel fuel in the county and statewide are required. The monthly distribution of sales is

TABLE 4-2. TABLE VM-2 FROM HIGHWAY STATISTICS^5--1979

CLASSIFIED BY FEDERAL-AID SYSTEM AND FUNCTIONAL CLASSIFICATION

(ROUNDED TO NEAREST MILLION VEHICLE-MILES OF TRAVEL)

TABLE VM-2
SEPTEMBER 1980

STATE	FEDERAL-AID HIGHWAYS											NON-FEDERAL-AID HIGHWAYS										ALL HIGHWAY CLASSES		
	INTERSTATE			PRIMARY			URBAN			SECONDARY	TOTAL FEDERAL-AID	ARTERIAL			COLLECTOR			LOCAL			TOTAL NON-FEDERAL-AID			
	ARTERIAL			ARTERIAL			ARTE-RIAL	COL-LECTOR	TOTAL	COLLECTOR														
	RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL	URBAN	URBAN		RURAL		RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL		RURAL	URBAN	TOTAL
ALABAMA	2,434	1,662	4,096	6,205	2,639	8,844	4,445	945	5,390	3,478	21,808	-	588	588	908	461	1,369	2,719	3,107	5,826	7,783	15,744	13,847	29,591
ALASKA	-	-	-	871	99	970	312	139	451	443	1,864	-	-	-	-	-	-	240	423	663	663	1,554	973	2,527
ARIZONA	3,171	1,138	4,309	2,999	988	3,987	6,507	586	7,093	2,311	17,700	-	-	-	111	95	206	586	1,092	1,678	1,884	9,178	10,406	19,584
ARKANSAS	2,002	862	2,864	4,512	1,633	6,145	1,221	183	1,404	1,221	11,634	299	437	736	1,609	312	1,921	1,233	765	1,998	4,655	10,876	5,413	16,289
CALIFORNIA	8,880	29,437	38,317	16,749	21,697	38,446	40,656	5,219	45,875	6,274	128,912	-	8,913	8,913	7,374	2,126	9,500	5,367	7,054	12,421	30,834	44,644	115,102	159,746
COLORADO	2,597	2,101	4,698	3,750	2,126	5,876	3,142	540	3,682	1,081	15,337	-	-	-	948	171	1,119	990	2,290	3,280	4,399	9,366	10,370	19,736
CONNECTICUT 2/	804	4,176	4,980	1,749	2,578	4,327	3,710	1,678	5,388	1,011	15,706	139	811	950	471	167	638	822	1,315	2,137	3,725	4,996	14,435	19,431
DELAWARE	143	498	641	1,125	527	1,652	584	176	760	398	3,451	1	2	3	45	12	57	302	280	582	642	2,014	2,079	4,093
DIST. OF COL.	-	335	335	-	1,008	1,008	1,006	320	1,326	-	2,669	-	86	86	-	6	6	-	573	573	665	-	3,334	3,334
FLORIDA 2/	4,574	5,603	10,177	11,477	10,833	22,310	13,973	4,139	18,112	2,928	53,527	2,079	1,488	3,567	572	724	1,296	3,432	12,829	16,261	21,124	25,062	49,589	74,651
GEORGIA	6,542	4,682	11,224	9,379	5,923	15,302	2,920	1,649	4,569	4,700	35,795	-	-	-	1,474	-	1,474	3,007	3,404	6,411	7,885	25,102	18,578	43,680
HAWAII 2/	136	592	728	1,040	898	1,938	370	140	510	306	3,482	5	46	51	112	144	256	265	706	971	1,278	1,864	2,896	4,760
IDAHO	1,238	242	1,480	1,576	126	1,702	782	305	1,087	1,057	5,326	-	-	-	128	-	128	826	1,289	2,115	2,243	4,825	2,744	7,569
ILLINOIS	5,126	8,379	13,505	8,816	10,093	18,909	12,833	5,458	18,291	3,766	54,471	-	228	228	1,445	190	1,635	2,841	5,754	8,595	10,458	21,994	42,935	64,929
INDIANA	5,052	3,905	8,957	7,056	2,999	10,055	8,393	3,511	11,904	3,574	34,490	189	63	252	764	45	809	1,647	3,031	4,678	5,739	18,282	21,947	40,229
IOWA	2,183	766	2,949	6,049	2,170	8,219	1,987	570	2,557	2,171	15,896	-	23	23	646	35	681	1,441	918	2,359	3,063	12,490	6,469	18,959
KANSAS 2/	1,727	1,124	2,851	4,860	1,245	6,105	2,326	267	2,593	2,158	13,707	54	656	710	254	349	603	1,220	1,212	2,432	3,745	10,273	7,179	17,452
KENTUCKY	3,273	1,665	4,938	5,236	2,536	7,772	4,175	1,173	5,348	4,619	22,677	-	-	-	1,829	204	2,033	1,129	1,618	2,747	4,780	16,086	11,371	27,457
LOUISIANA 2/	2,438	1,768	4,206	4,410	2,338	6,748	1,750	1,050	2,800	4,617	18,371	-	630	630	1,168	330	1,498	1,630	1,260	2,890	5,018	14,263	9,126	23,389
MAINE	913	180	1,093	1,983	551	2,534	753	216	969	1,052	5,648	107	38	145	560	2	562	535	222	757	1,464	5,150	1,962	7,112
MARYLAND	2,015	4,406	6,421	4,917	3,365	8,282	6,209	1,106	7,315	1,997	24,015	11	80	91	861	467	1,328	1,104	1,297	2,401	3,820	10,905	16,930	27,835
MASSACHUSETTS	1,306	6,018	7,324	2,598	7,545	10,143	10,062	2,545	12,607	1,573	31,647	-	78	78	746	163	909	396	2,148	2,544	3,531	6,619	28,559	35,178
MICHIGAN	3,231	5,505	8,736	8,431	6,289	14,720	21,994	2,314	24,308	5,237	53,001	-	216	216	1,234	849	2,083	3,234	6,366	9,600	11,899	21,367	43,533	64,900
MINNESOTA	2,109	2,643	4,752	6,684	2,390	9,074	4,106	424	4,530	2,737	21,093	33	148	181	846	1,502	2,348	2,391	1,902	4,293	6,822	14,800	13,115	27,915
MISSISSIPPI	1,931	660	2,591	5,243	1,188	6,431	1,832	580	2,412	3,124	14,558	112	5	117	255	-	255	1,072	1,186	2,258	2,630	11,737	5,451	17,188
MISSOURI	3,623	4,910	8,533	6,646	2,683	9,329	5,700	895	6,595	4,044	28,501	55	874	929	356	697	1,053	2,504	1,574	4,078	6,060	17,228	17,333	34,561
MONTANA	1,359	83	1,442	2,036	329	2,365	548	54	602	428	4,837	17	109	126	258	100	358	1,212	170	1,382	1,866	5,310	1,393	6,703
NEBRASKA	1,360	463	1,823	3,588	1,227	4,815	1,379	330	1,709	989	9,336	-	-	-	305	-	305	1,155	733	1,888	2,193	7,397	4,132	11,529
NEVADA 2/	954	295	1,249	1,012	163	1,175	1,792	24	1,816	672	4,912	-	12	12	109	242	351	278	337	615	978	3,025	2,865	5,890
NEW HAMPSHIRE	681	359	1,040	1,665	596	2,261	491	398	889	757	4,947	99	57	156	260	3	263	817	165	982	1,401	4,283	2,065	6,348
NEW JERSEY 2/	1,018	4,911	5,929	3,119	7,035	10,154	13,900	3,041	16,941	2,497	35,521	1,247	2,711	3,958	934	34	968	767	9,183	9,950	14,876	9,582	40,815	50,397
NEW MEXICO	2,088	591	2,679	2,815	611	3,426	1,807	276	2,083	774	8,962	-	96	96	290	154	444	740	1,116	1,856	2,396	6,707	4,651	11,358
NEW YORK	3,902	8,015	11,917	9,305	16,458	25,763	20,381	2,480	22,861	3,539	64,080	-	182	182	1,583	322	1,905	3,569	8,074	11,643	13,730	21,898	55,912	77,810
NORTH CAROLINA	3,628	1,614	5,242	9,959	3,637	13,596	4,282	152	4,434	6,763	30,035	127	2,750	2,877	2,130	544	2,674	2,512	3,977	6,489	12,040	25,119	16,956	42,075
NORTH DAKOTA	699	111	810	1,780	374	2,154	304	145	449	682	4,095	-	4	4	212	8	220	710	205	915	1,139	4,083	1,151	5,234
OHIO 2/	6,971	10,881	17,852	8,838	7,418	16,256	6,788	4,276	11,064	6,759	51,931	-	-	-	2,350	-	2,350	6,532	12,411	18,943	21,293	31,450	41,774	73,224
OKLAHOMA	2,812	1,863	4,675	5,251	1,400	6,651	5,249	816	6,065	3,100	20,491	256	120	376	1,492	326	1,818	1,516	2,555	4,071	6,265	14,427	12,329	26,756
OREGON	2,442	1,356	3,798	4,442	2,085	6,527	1,391	1,233	2,624	1,371	14,320	174	44	218	1,191	213	1,404	2,725	870	3,595	5,217	12,345	7,192	19,537
PENNSYLVANIA	6,365	3,803	10,168	15,033	10,900	25,933	9,226	3,587	12,813	5,122	54,036	-	-	-	2,409	-	2,409	5,238	8,603	13,841	16,250	34,167	36,119	70,286
RHODE ISLAND	163	969	1,132	552	1,012	1,564	1,392	411	1,803	168	4,667	-	-	-	109	-	109	298	825	1,123	1,232	1,290	4,609	5,899
SOUTH CAROLINA	2,810	890	3,700	7,430	1,880	9,310	2,424	250	2,674	4,130	19,814	-	540	540	450	335	785	2,010	925	2,935	4,260	16,830	7,244	24,074
SOUTH DAKOTA	1,040	118	1,158	2,035	437	2,472	359	46	405	673	4,708	2	1	3	163	77	240	509	154	663	906	4,422	1,192	5,614
TENNESSEE 2/	4,910	3,001	7,911	6,925	4,079	11,004	4,237	1,330	5,567	3,248	27,730	-	-	-	-	-	-	2,432	3,922	6,354	6,354	17,515	16,569	34,084
TEXAS	8,672	14,764	23,436	19,239	11,783	31,022	17,758	1,369	19,127	10,589	84,174	-	102	102	1,908	75	1,983	4,767	18,734	23,501	25,586	45,175	64,585	109,760
UTAH	1,411	1,330	2,741	1,472	302	1,774	2,260	679	2,939	660	8,114	-	26	26	314	88	402	669	600	1,269	1,697	4,526	5,285	9,811
VERMONT	642	46	688	993	185	1,178	222	125	347	824	3,037	-	-	-	189	-	189	341	147	488	677	2,989	725	3,714
VIRGINIA	4,311	3,716	8,027	8,142	2,624	10,766	5,834	1,354	7,188	4,910	30,891	136	197	333	315	10	325	2,179	4,750	6,929	7,587	19,993	18,485	38,478
WASHINGTON	2,475	4,563	7,038	4,904	3,165	8,069	3,889	2,822	6,711	2,726	24,544	-	-	-	878	20	898	473	3,207	3,680	4,578	11,456	17,666	29,122
WEST VIRGINIA	1,312	639	1,951	2,769	674	3,443	1,165	434	1,599	2,791	9,784	8	12	20	326	1	327	858	590	1,448	1,795	8,064	3,515	11,579
WISCONSIN	2,750	1,743	4,493	9,798	4,504	14,302	3,030	550	3,580	2,890	25,265	15	206	221	848	1,063	1,911	1,557	4,020	5,577	7,709	17,858	15,116	32,974
WYOMING	1,370	79	1,449	1,389	260	1,649	233	169	402	410	3,906	93	1	94	170	14	184	317	281	598	876	3,749	1,033	4,782
TOTAL U.S.	133,597	159,452	293,049	268,852	179,605	448,457	272,089	62,479	334,568	133,349	1,209,423	5,258	22,580	27,838	43,909	12,680	56,589	85,114	150,169	235,283	319,710	670,079	859,054	1,529,133
PUERTO RICO 3/	-	-	-	2,205	2,681	4,886	1,519	515	2,034	403	7,323	-	-	-	192	400	592	311	924	1,235	1,827	3,111	6,039	9,150
GRAND TOTAL	133,597	159,452	293,049	271,057	182,286	453,343	273,608	62,994	336,602	133,752	1,216,746	5,258	22,580	27,838	44,101	13,080	57,181	85,425	151,093	236,518	321,537	673,190	865,093	1,538,283

1/ DATA PRESENTED IN THIS TABLE SHOULD BE REGARDED AS PRELIMINARY; A NEW TABLE WILL BE ISSUED LATER.

2/ STATE HIGHWAY AGENCY ESTIMATE SUBJECT TO REVISION PENDING FURTHER FEDERAL HIGHWAY ADMINISTRATION REVIEW.

3/ FEDERAL HIGHWAY ADMINISTRATION ESTIMATES WERE MADE FOR THE VARIOUS HIGHWAY CLASSES.

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also required. Note that each state reports monthly fuel sales data to the Federal Highway Administration, which, in turn, reports various fuel use statistics in Highway Statistics[5], and in a monthly publication.[6]

The apportioning factor is the ratio of county motor fuel use to state fuel use. Tables MF-25 and MF-26, respectively, in Highway Statistics[5] tabulate the monthly highway use of special fuels and gasoline for each state in the U.S. Special fuels are essentially diesel fuel and some liquified petroleum gases. Table MF-26 indicates the actual use of gasoline and gasohol by highway vehicles; the data shown in that table have been adjusted to account for handling losses and exclude gasoline used for nonhighway purposes. The VMT apportioning factor is:

$$f_c = \frac{Q_c}{Q_s} \qquad (4\text{-}1)$$

where f_c = the apportioning factor to be applied to statewide VMT to estimate county VMT;

Q_c = the total quantity (gallons) of gasoline and diesel fuel sold in the county, obtained from the state revenue agency; and

Q_s = the total quantity (gallons) of gasoline and diesel fuel sold in the state, obtained from the state revenue agency or from Tables MF-25 and MF-26 in Highway Statistics.[5]

Another method for allocating VMT to a county is to use roadway inventory data--that is, an inventory of roadway mileage by functional category--representing both the statewide and county highway network. The underlying assumption in this method is that VMT is generally a function of total roadway mileage, and that ~~this~~ functional relationship becomes more direct as individual types of highways within specific areas are considered.

State transportation and highway agencies report total roadway mileage by functional type (i.e., interstate, primary arterials, arterials, collectors, and local streets) in both urbanized and rural areas, for both the Federal-aid and non-Federal aid portions of the highway system. A summary of these data is published by FHWA in Highway Statistics[5] as Table M-12, which is shown here as Table 4-3. As Tables 4-3 and 4-2 show, roadway mileage and VMT are reported in exactly the same format--that is, by functional type on Federal-aid and non-Federal aid highways in both urban and rural portions of each state. One additional set of data is required--the county roadway mileage disaggregated by the same categories as those for the statewide data. This information should be available directly from the state transportation agency or it can be derived based on input from both state and county transportation agencies.

The VMT allocation factor is then derived as the ratio of county to state roadway mileage for each category of highway in both rural or urban areas:

TABLE 4-3. TABLE M-12 FROM HIGHWAY STATISTICS[5]--1979

TOTAL ROAD AND STREET MILEAGE - 1979[1]

CLASSIFIED BY FEDERAL-AID SYSTEM AND FUNCTIONAL CLASSIFICATION

MILEAGE AS OF DECEMBER 31,1979

TABLE M-12
SEPTEMBER 1980

STATE	FEDERAL-AID HIGHWAYS											NON-FEDERAL-AID HIGHWAYS										ALL HIGHWAY CLASSES		
	INTERSTATE			PRIMARY			URBAN			SECONDARY	TOTAL FEDERAL-AID										TOTAL NON-FEDERAL-AID			
	ARTERIAL			ARTERIAL			ARTE-RIAL	COL-LECTOR	TOTAL	COLLECTOR		ARTERIAL			COLLECTOR			LOCAL						
	RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL	URBAN	URBAN		RURAL		RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL	RURAL	URBAN	TOTAL		RURAL	URBAN	TOTAL
ALABAMA	629	162	791	5,923	702	6,625	1,385	788	2,173	11,016	20,605	-	240	240	7,166	648	7,814	48,690	9,785	58,475	66,529	73,424	13,710	87,134
ALASKA	-	-	-	2,110	19	2,129	90	15	105	1,745	3,979	-	-	-	-	-	-	5,301	483	5,784	5,784	9,156	607	9,763
ARIZONA	1,046	86	1,132	3,232	158	3,390	1,107	477	1,584	3,588	9,694	-	-	-	5,630	465	6,095	37,226	6,842	44,068	50,163	50,722	9,135	59,857
ARKANSAS	430	100	530	4,715	425	5,140	660	223	883	6,222	12,775	595	414	1,009	10,559	626	11,185	45,423	4,279	49,702	61,896	67,944	6,727	74,671
CALIFORNIA	1,516	891	2,407	9,767	1,333	11,100	11,049	4,436	15,485	10,716	39,708	-	2,706	2,706	13,522	2,520	16,042	80,815	38,534	119,349	138,097	116,336	61,469	177,805
COLORADO	831	110	941	3,974	292	4,266	1,656	515	2,171	3,462	10,840	-	-	-	17,202	458	17,660	46,141	6,296	52,437	70,097	71,610	9,327	80,937
CONNECTICUT	80	208	288	762	474	1,236	1,187	1,599	2,786	930	5,240	23	102	125	1,256	172	1,428	6,287	6,218	12,505	14,058	9,338	9,960	19,298
DELAWARE	7	34	41	349	78	427	162	118	280	632	1,380	2	3	5	165	20	185	2,732	947	3,679	3,869	3,887	1,362	5,249
DIST. OF COL.	-	12	12	-	77	77	181	137	318	-	407	-	18	18	-	4	4	-	671	671	693	-	1,100	1,100
FLORIDA	796	330	1,126	6,072	1,656	7,728	2,188	2,803	4,991	4,602	18,447	649	359	1,008	5,502	1,452	6,954	47,153	22,719	69,872	77,834	64,774	31,507	96,281
GEORGIA	937	223	1,160	8,907	1,241	10,148	1,334	1,456	2,790	14,118	28,216	-	-	-	7,549	-	7,549	56,814	11,154	67,968	75,517	88,325	15,408	103,733
HAWAII	13	25	38	444	67	511	140	55	195	415	1,159	3	7	10	272	70	342	1,529	768	2,297	2,649	2,676	1,132	3,808
IDAHO	567	45	612	2,586	33	2,619	217	240	457	4,034	7,722	-	-	-	4,322	-	4,322	51,444	3,040	54,484	58,806	62,953	3,575	66,528
ILLINOIS	1,293	409	1,702	7,971	1,699	9,670	3,323	2,720	6,043	12,793	30,208	-	106	106	5,213	222	5,435	79,262	19,232	98,494	104,035	106,532	27,711	134,243
INDIANA	857	263	1,120	4,141	733	4,874	3,079	1,717	4,796	8,742	19,532	110	15	125	11,185	128	11,313	48,503	11,861	60,364	71,802	73,538	17,796	91,334
IOWA	612	118	730	8,248	659	8,907	1,300	895	2,195	13,288	25,120	-	19	19	16,374	89	16,463	65,519	4,786	70,305	86,787	104,041	7,866	111,907
KANSAS	669	131	800	7,806	305	8,111	941	442	1,383	22,514	32,808	49	208	257	9,418	270	9,688	86,849	5,382	92,231	102,176	127,305	7,679	134,984
KENTUCKY	541	114	655	3,494	425	3,919	1,043	705	1,748	7,270	13,592	-	-	-	9,430	116	9,546	41,674	4,138	45,812	55,358	62,409	6,541	68,950
LOUISIANA	536	127	663	2,722	375	3,097	670	668	1,338	7,427	12,525	-	312	312	4,396	333	4,729	30,580	7,693	38,273	43,314	45,661	10,178	55,839
MAINE	281	33	314	1,840	158	1,998	328	309	637	2,767	5,716	44	14	58	2,761	23	2,784	11,934	1,318	13,252	16,094	19,627	2,183	21,810
MARYLAND	201	180	381	1,746	372	2,118	1,295	615	1,910	2,031	6,440	11	16	27	2,054	366	2,420	10,917	6,815	17,732	20,179	16,960	9,659	26,619
MASSACHUSETTS	180	334	514	1,085	1,136	2,221	3,186	2,438	5,624	2,108	10,467	-	26	26	2,066	172	2,238	8,515	12,374	20,889	23,153	13,954	19,666	33,620
MICHIGAN	716	408	1,124	6,242	870	7,112	4,684	908	5,592	17,288	31,116	-	58	58	6,763	579	7,342	68,148	13,416	81,564	88,964	99,157	20,923	120,080
MINNESOTA	694	163	857	8,778	467	9,245	1,308	415	1,723	16,305	28,130	101	106	207	11,901	1,143	13,044	79,496	8,336	87,832	101,083	117,275	11,938	129,213
MISSISSIPPI	575	78	653	5,312	275	5,587	811	597	1,408	11,730	19,378	235	5	240	2,926	-	2,926	42,955	3,941	46,896	50,062	63,733	5,707	69,440
MISSOURI	828	269	1,097	6,354	454	6,808	1,781	368	2,149	18,110	28,164	39	809	848	5,485	1,110	6,595	73,201	8,850	82,051	89,494	104,017	13,641	117,658
MONTANA	1,157	35	1,192	5,363	87	5,450	249	81	330	4,699	11,671	56	49	105	11,210	139	11,349	52,162	1,553	53,715	65,169	74,647	2,193	76,840
NEBRASKA	648	36	684	7,028	279	7,307	574	344	918	11,149	20,058	-	-	-	11,695	-	11,695	61,814	2,894	64,708	76,403	92,334	4,127	96,461
NEVADA	461	21	482	1,823	23	1,846	336	14	350	2,393	5,071	-	10	10	2,554	141	2,695	41,037	1,125	42,162	44,867	48,268	1,670	49,938
NEW HAMPSHIRE	181	44	225	1,012	127	1,139	284	299	583	1,263	3,210	21	13	34	1,238	19	1,257	9,917	1,245	11,162	12,453	13,632	2,031	15,663
NEW JERSEY	110	221	331	853	601	1,454	3,299	1,807	5,106	1,882	8,773	148	219	367	1,430	35	1,465	8,198	14,593	22,791	24,623	12,621	20,775	33,396
NEW MEXICO	865	72	937	4,153	146	4,299	461	177	638	3,231	9,105	-	35	35	3,401	195	3,596	55,783	4,081	59,864	63,495	67,433	5,167	72,600
NEW YORK	808	555	1,363	6,503	1,885	8,388	5,156	2,767	7,923	6,348	24,022	-	72	72	10,983	395	11,378	48,514	25,291	73,805	85,255	73,156	36,121	109,277
NORTH CAROLINA	609	133	742	4,133	557	4,690	1,371	185	1,556	10,294	17,282	249	1,461	1,710	9,757	986	10,743	52,638	9,930	62,568	75,021	77,680	14,623	92,303
NORTH DAKOTA	542	29	571	5,487	121	5,608	158	191	349	10,900	17,428	-	1	1	7,577	24	7,601	80,563	776	81,339	88,941	105,069	1,300	106,369
OHIO	883	637	1,520	5,227	1,564	6,791	3,376	3,894	7,270	11,560	27,141	-	-	-	7,244	-	7,244	56,701	19,083	75,784	83,028	81,615	28,554	110,169
OKLAHOMA	681	143	824	5,077	335	5,412	1,536	584	2,120	8,534	16,890	223	79	302	16,408	473	16,881	67,422	8,236	75,658	92,841	98,345	11,386	109,731
OREGON	584	118	702	4,669	303	4,972	908	828	1,736	7,703	15,113	178	19	197	9,411	131	9,542	84,643	5,761	90,404	100,143	107,188	8,068	115,256
PENNSYLVANIA	1,183	322	1,505	8,035	1,813	9,848	2,670	4,026	6,696	8,177	26,226	-	-	-	9,213	-	9,213	61,586	20,382	81,968	91,181	88,194	29,213	117,407
RHODE ISLAND	28	44	72	214	188	402	448	372	820	166	1,460	-	-	-	221	-	221	2,139	2,576	4,715	4,936	2,768	3,628	6,396
SOUTH CAROLINA	624	78	702	5,053	397	5,450	631	179	810	8,855	15,817	-	298	298	4,097	535	4,632	36,296	5,044	41,340	46,270	54,925	7,162	62,087
SOUTH DAKOTA	590	34	624	5,769	114	5,883	251	78	329	10,816	17,652	14	5	19	7,361	58	7,419	56,699	776	57,475	64,913	81,249	1,316	82,565
TENNESSEE	835	188	1,023	5,477	793	6,270	1,147	1,087	2,234	9,478	19,005	-	-	-	-	-	-	56,938	6,696	63,634	63,634	72,728	9,911	82,639
TEXAS	2,099	800	2,899	15,412	1,708	17,120	5,151	1,471	6,622	32,450	59,091	-	87	87	20,500	146	20,646	140,343	44,692	185,035	205,768	210,804	54,055	264,859
UTAH	664	105	769	2,486	69	2,555	412	255	667	2,549	6,540	-	45	45	4,506	210	4,716	32,149	3,025	35,174	39,935	42,354	4,121	46,475
VERMONT	302	8	310	1,046	48	1,094	113	100	213	1,990	3,607	-	-	-	1,037	-	1,037	8,968	422	9,390	10,427	13,343	691	14,034
VIRGINIA	757	196	953	4,949	440	5,389	1,876	983	2,859	10,399	19,600	308	56	364	2,389	23	2,412	34,404	8,386	42,790	45,566	53,206	11,960	65,166
WASHINGTON	428	231	659	4,514	512	5,026	2,185	1,776	3,961	7,115	16,761	51	2	53	7,040	10	7,050	50,444	9,924	60,368	67,471	69,592	14,640	84,232
WEST VIRGINIA	390	86	476	2,248	172	2,420	386	393	779	6,318	9,993	10	4	14	2,266	4	2,270	21,956	2,169	24,125	26,409	33,188	3,214	36,402
WISCONSIN	429	95	524	8,037	931	8,968	1,744	832	2,576	11,879	23,947	30	182	212	8,525	520	9,045	65,643	8,473	74,116	83,373	94,543	12,777	107,320
WYOMING	841	30	871	2,947	79	3,026	128	137	265	2,288	6,450	248	6	254	7,547	28	7,575	20,691	716	21,407	29,236	34,562	1,124	35,686
TOTAL U.S.	31,334	9,114	40,448	232,095	27,775	259,870	79,995	48,479	128,474	396,489	825,281	3,397	8,186	11,583	330,727	15,058	345,785	2,284,756	427,727	2,712,483	3,069,851	3,278,798	616,334	3,895,132
PUERTO RICO 2/	-	-	-	472	175	647	170	145	315	727	1,689	-	-	-	2,530	160	2,690	1,100	2,250	3,350	6,040	4,829	2,900	7,729
GRAND TOTAL	31,334	9,114	40,448	232,567	27,950	260,517	80,165	48,624	128,789	397,216	826,970	3,397	8,186	11,583	333,257	15,218	348,475	2,285,856	429,977	2,715,833	3,075,891	3,283,627	619,234	3,902,861

1/ DATA OBTAINED FROM TABLE TA-1 AS SUBMITTED BY STATE HIGHWAY AGENCIES. MILEAGES PRESENTED IN THIS TABLE SHOULD BE REGARDED AS PRELIMINARY; A NEW TABLE WILL BE ISSUED LATER. FIGURES HAVE BEEN ROUNDED TO NEAREST MILE.

2/ FEDERAL HIGHWAY ADMINISTRATION ESTIMATES WERE MADE FOR VARIOUS HIGHWAY CLASSES.

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$$f_{ci} = \frac{M_{ci}}{M_{si}} \qquad (4\text{-}2)$$

where f_{ci} = the apportioning factor to be applied to statewide VMT to estimate county VMT for roadway type i,

M_{ci} = miles of type i roadway in the county, and

M_{si} = miles of type i roadway in the state.

The result will be as many as 13 individual allocation factors in each county, each of which is applied to the corresponding VMT figure in Table VM-2 from Highway Statistics[5] (see Table 4-2, here).

A third method for allocating statewide VMT to the county level utilizes motor vehicle registration data to derive an apportioning factor. The premise here is that the amount of travel (VMT) occurring in an area is a function of the area's vehicle population. This method assumes that travel by vehicles registered outside the area is balanced by travel outside the area by vehicles registered in the area and that average county travel patterns are not significantly different from the statewide (or other) averages. Since this overall method applies to rural counties or small urban areas, the assumption is that travel characteristics are generally consistent within all areas of the state regardless of the differences that may exist among the areas in their degree of urbanization.

The allocation factor is the ratio of county registered vehicles to state registered vehicles. Registration statistics can be obtained from the state motor vehicle registration department for both the state and county, although there may be a requirement for special processing of state registration files to produce county-specific data. The factor is defined by:

$$f_c = \frac{V_c}{V_s} \qquad (4\text{-}3)$$

where f_c = the allocation factor to be applied to statewide VMT to derive county VMT,

V_c = total number of motor vehicles of all types registered in the county, and

V_s = total number of motor vehicles of all types registered in the state.

Finally, statewide VMT can be apportioned to the county level based on the relative county and state population. This method has the advantage of utilizing data that are routinely available from several sources, such as the Bureau of Census and state and county agencies, and therefore VMT estimates can be developed with minimal effort. A disadvantage to this method is that population data may not be current. In addition, this method is perhaps the least sensitive to variations in travel characteristics among different types of areas and therefore may be the least accurate. The apportioning factor is:

$$f_c = \frac{P_c}{P_s} \qquad (4\text{-}4)$$

where f_c = the allocation factor to be applied to statewide VMT to derive county VMT,

P_c = county population, and

P_s = state population.

4.4.2.2 County VMT Computation

County level VMT is estimated by applying the allocation factor, f_c, to statewide VMT statistics obtained from the state transportation agency, or from Table VM-2 in Highway Statistics[5] (see Table 4-2). Expressed as an equation, the estimated annual VMT occurring in the county is:

$$VMT_c = f_c \times VMT_s \qquad (4\text{-}5)$$

where VMT_c = estimated annual county VMT,

VMT_s = total statewide VMT, from the state transportation agency or from Table VM-2 in Highway Statistics[5], and

f_c = apportioning factor derived from one of equations 4-1 through 4-4.

In all instances except where the apportioning factor is based on roadway mileage (Equation 4-2), the value assigned to VMT_s is found in the TOTAL column for ALL HIGHWAY CLASSES in Table 4-2. If equation 4-2 is used, the individual values of VMT for each roadway type in urban and rural areas in Table 4-2 are used for VMT_s.

4.4.2.3 Disaggregation of VMT_c by Roadway Type

Emissions from motor vehicles are greatly affected by travel speed, which in turn is directly related to the type of roadway. Defining the distribution of VMT by roadway type enables a general distribution of VMT by roadway speed to be derived.

The basis for deriving VMT distributions by roadway type is the relative county and state mileage of each functional category (i.e., interstate, primary arterial, arterial, collector, and local street). The process is the same one described in 4.4.2.2 for allocating statewide VMT to the county level based on roadway mileage. The advantage to using this method of allocation is that it provides a direct estimate of county VMT by functional category.

If some other method for allocating state VMT to the county is used, the extra step of deriving an estimate of county VMT distribution by roadway type is necessary. This can be done using the same method of comparing county roadway mileage to state roadway mileage for each functional category, and applying the resulting allocation factor to the appropriate VMT by functional category figures found in Table 4-2. Each value thus derived is expressed as a percentage of the total VMT computed for the county using this procedure, and applied to the actual county VMT value. Expressed as an equation:

$$VMT_{ci} = \left[\frac{f_{ci} \times VMT_{si}}{\sum_{i=1}^{n} (f_{ci} \times VMT_{si})} \right] \times \left| \sum VMT_c \right| \qquad (4\text{-}6)$$

where VMT_{ci} = the derived value of VMT occurring on roadway functional category i in the county;

f_{ci} = apportioning factor derived using Equation 4-2;

VMT_{si} = statewide VMT on functional category i, obtained from Table VM-2 in Highway Statistics[5] (see Table 4-2); and

VMT_c = total VMT derived for the county using whatever method is deemed appropriate.

The actual purpose served by deriving VMT_c by roadway functional category is to provide a rationale for assigning travel speeds. The intent is to assign a value to each type of roadway representing the average travel speed over the entire network of that functional category. This may be based on a combination of actual travel speed data and engineering judgment. States have generally monitored speeds on the interstate system and on other controlled access, divided highways, therefore, some speed data for these types of highways can be expected to exist. For other types of roads data may not exist, therefore estimates based on competent engineering judgment will be required. The intent is to establish an estimate of the average speed over the entire system, which is somewhat lower than the free flowing speed since it must reflect delays, slowdowns, and normal interruptions in traffic flow. Where no data exist, assistance should be solicited from state or county transportation engineers to develop estimates.

Once average speed values have been assigned, VMT can be aggregated by general functional category (i.e., limited access highways, primary arterials, arterials, collectors, and local streets), where each category has a specific speed associated with it.

4.4.2.4 Disaggregation of VMT by Vehicle Type

Since emission rates, in grams or pounds of pollutant per vehicle-mile of travel, are characteristically different for each of several vehicle categories, the VMT data must be further disaggregated to reflect the relative travel by each vehicle type. Several methods for deriving an estimate of the relative travel by vehicle type are discussed here.

The first method is to merely accept the default distribution of VMT by vehicle types contained in the MOBILE2. This distribution was derived by the U.S. Environmental Protection Agency based on national statistics, and changes slightly by calendar year to account for the apparent trend towards the use of diesel engines for all classes of motor vehicles. In view of the general nature of other data elements used in the inventorying process, the default values for distributing VMT by vehicle type are appropriate. However, the default values for rural areas in MOBILE2 may not be appropriate for those rural areas that experience a large amount of through truck traffic. In these cases, the actual distribution of vehicle types could be significantly different than the default distribution values.

If it is decided that local characterization of the VMT distribution is warranted, then one of two methods can be utilized to derive the appropriate distributions. The first method is to obtain traffic classification data from state, county, and local highway agencies. That data can be used to develop representative distributions of vehicle type as a function of roadway category. Traffic classification counts are typically made by highway agencies as part of their ongoing traffic data collection programs, therefore, these agencies should be considered the primary source for this information. Classification data should be obtained for each functional category of roadway. Although the first choice should be to obtain data for highways located in the specific area being inventoried, data from other, similar areas can be used.

Typical vehicle categories used in classification counts include:

- Passenger cars
    - standard
    - compact
    - subcompact
- Panel and Pickup Trucks
- Single-unit Trucks
    - 2-axle, 4-wheel
    - 2-axle, 6 wheel

    - 3-axle
    - 4-axle
- Combinations
    - 2-axle tractor, 1-axle trailer
    - 2-axle tractor, 2-axle trailer
    - 3-axle tractor, 2-axle trailer
    - 3-axle tractor, 3-axle trailer
- Buses
    - Commercial
    - Nonrevenue
- Motorcycles
- Miscellaneous

On the other hand, the vehicle categories that are of interest in terms of emission inventory development are those discussed previously in Section 4.1 (e.g., LDGV, LDDV, LDGT1, etc). The relationship between the vehicle categories used in emission inventories and those typically available from classification counts is shown in Table 4-4.

Typically, classification counts do not distinguish diesel from gasoline-powered vehicles as Table 4-4 shows. However, this disaggregation is required for emission inventories, as the engine types have quite different emission characteristics. National average values are available in MOBILE2. They are:

Light-duty vehicles	- gasoline	99.7%
	- diesel	0.3%
Light-duty trucks	- 1	63.6%
	- 2	36.1%
	- diesel	0.3%
Heavy-duty vehicles	- gasoline	54.2%
	- diesel	45.8%

These figures can be used unless better local data are available.

TABLE 4-4. VEHICLE CATEGORIES

Emission inventories	Classification counts
LDGV LDDV	Passenger cars (all types)
LDGT1	Panel and pickup trucks
LDGT2	Single unit trucks, 2-axle, 4-wheel
LDDT	Panel and pickup trucks Single unit trucks, 2-axle, 4-wheel
HDGV HDDV	Single unit trucks (all other types) Combinations (all types) Buses (all types)
MC	Motorcycles

The relative proportions of HDGV's and HDDV's can also be estimated using data provided in the 1977 Census of Transportation--Truck Inventory and Use Survey.[7] Table 4, for example, in the U.S. report provides an indication of the relative number of gasoline and diesel powered trucks according to 4 vehicle categories:

light;

medium;

light-heavy; and

heavy-heavy.

The "light" category includes vehicles 10,000 pounds gross vehicle weight (GVW) or less, which are essentially panels, pickups and 2-axle, 4-wheel trucks. For purposes here, all of these can be considered LDGT1's and LDGT2's. The other three categories would all be heavy duty vehicles. These categories can also be disaggregated based on the type of engine--gasoline or diesel--also using the Census of Transportation.[7] The results are shown in Table 4-5. The TOTAL line provides a distribution of gasoline and diesel vehicles for various subsets of single-unit and combination vehicles that can be used with state classification counts to identify the percentage of HDGV and HDDV for each type of roadway. Referring to the vehicle classifications used in quantifying emissions, all vehicles represented in Table 4-5 are either HDGV or HDDV. The same type of table can be developed from state data contained in the individual state Truck Inventory and Use Surveys,[7] although there should not be a significant difference in the final distribution of gasoline to diesel-powered vehicles.

The second method for deriving a distribution of VMT by vehicle type is to assume that the distribution is a function of the number of each type of vehicle registered in the county or the state. This method does not require that the total county VMT be disaggregated to VMT by roadway type (see Figure 4-1). Instead, the percentage of each vehicle type is determined from registration records and the total county VMT is disaggregated to VMT by vehicle type with that data.

The data required consist of a detailed record of the number of motor vehicles registered in the county, by vehicle type. The specific vehicle categories that should be identified are those delineated here in Section 4.1, although LDDV's and LDDT's are generally so few in number that it can be assumed that they are respectively included with the LDGV, and LDGT1 and LDGT2 categories. Motor vehicle registration statistics routinely maintained by many states may yield this information directly. Alternatively, special processing may be required to tabulate the registration statistics at county level. In lieu of county-specific data, the state vehicle population statistics may be applied.

TABLE 4-5. DISTRIBUTION OF GASOLINE AND DIESEL-POWERED HEAVY-DUTY VEHICLES BY VEHICLE CONFIGURATION[a]

	SINGLE-UNIT VEHICLES						COMBINATIONS								
	2-axle			3-axle			3-axle			4-axle			5-axle		
Category	Gasoline	Diesel	Total	Gasoline	Diesel	Total	Gasoline	Diesel	Total	Gasoline	Diesel	Total	Gasoline	Diesel	Total
Medium	58	1	59	9	-	9	2	1	3	-	1	1	-	-	-
Light-Heavy	26	2	28	11	1	12	7	5	12	2	4	6	-	1	1
Heavy-Heavy	5	8	13	37	42	79	50	35	85	35	62	93	1	98	99
Total	89	11	100	57	43	100	59	41	100	33	67	100	1	99	100

[a] Derived from Reference 7 based on nationwide data.

The apportioning factor for each vehicle type, then, is:

$$f_{vi} = \frac{N_i}{\sum_{i=1}^{n} N_i} \tag{4-7}$$

where f_{vi} = apportioning factor for vehicle type i, to be applied to VMT_c; and

N_i = number of type i vehicles registered in the county or state.

This method does not account for differences in the annual mileage accrual among vehicle types. For example, some HDDV's may travel over 100,000 miles annually whereas LDG's typically travel about 10,000 miles per year. Although statistics are available regarding the average annual mileage accrual by various vehicle categories, these cannot be applied to travel occurring within a relatively small area such as a county. Table 13 in Reference 7 provides information on annual mileage by truck type, by typical range of operation. The range of operation categories include local, short-range (generally, within 200 miles of the base of operation), and long-range (beyond 200 miles of the base of operation).* That table shows significant differences among all categories of trucks in terms of annual mileage accrual and range of operation. A significant portion of the mileage accrued annually by trucks in the short-range category, and most of the mileage accrued by vehicles in the long-range class can be expected to occur outside the general area (county, for example) where the vehicle is registered. A VMT weighing factor based on annual miles traveled would not be appropriate for application at the county level. In the absence of specific data regarding the relative amount of countywide travel by each vehicle category, it must be assumed that the relative number of vehicles in each category provides an adequate indication of the actual distribution of VMT, by vehicle type.

4.4.2.5 Special Requirements

It is often necessary to compute the average daily (weekday) highway vehicle emissions during the peak ozone or carbon monoxide seasons. Daily vehicle emissions are required for SIP revisions, for example. In these cases, the activity factor for highway vehicles (VMT by vehicle type) must be developed to reflect daily VMT. Total annual VMT from Table 4-2 can be adjusted to reflect average weekday VMT during the summer months (June through August) for ozone, and during the winter months (November through February) for carbon monoxide by the following procedure.

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*A fourth category--off the road--is included in Table 13. Vehicles in this classification, however, are not accounted for in the on-highway emission source category and are therefore not considered.

All states maintain ongoing traffic counting programs, which can provide information concerning daily and seasonal variations in traffic flow. The particular seasonal pattern for an area is affected largely by the nature of the area. Therefore, it is not possible to develop general rules that would apply in all instances. If average daily emissions during the peak pollutant season are to be considered, the total VMT from Table 4-2 should first be divided by 365 to yield a value for the estimated average annual daily VMT, which is similar in concept to average annual daily traffic (AADT). Average daily traffic (ADT) patterns for each month are developed by the state highway agencies depicting the ADT as a function of AADT. The same relationship that exists between ADT during the peak pollutant season and the AADT can then be assumed to exist between daily VMT and average annual daily VMT.

4.4.3 CALCULATION OF EMISSIONS

The actual calculation of emissions from highway vehicles is accomplished using emission factors calculated from the MOBILE2 emission model, and the activity factors. The MOBILE2 User's Guide[2] must be consulted for a detailed explanation of MOBILE2 use, as it is too lengthy for inclusion here. This section does, however, discuss the additional requirements for local input necessary to calculate emission factors using MOBILE2.

Input data for MOBILE2 includes a one-time data set and an emission factor parameter data set. The first element in the one-time data set is the VMT distribution by vehicle type (the activity factor). In developing the activity factor, three possibilities exist:

a single distribution of VMT by vehicle-type;

a unique distribution of VMT by vehicle-type defined as a function of roadway functional category; or

use of the default vehicle-type distributions contained as a subprogram in MOBILE2.

The next element in the one-time data set relates to the mileage accrual by vehicle type and age characteristics of the vehicle population. For purposes here, the default option, which is based on national data, should be specified unless local data are available.

Next is a data element pertaining to the baseline emission rates for the vehicle population. The user can specify rates that are different from those contained in the MOBILE2 program, however, for most applications the user should specify the MOBILE2 emission rates.

Since the baseline emission rates for motor vehicles are affected by motor vehicle inspection and maintenance (I/M) programs, the data set must contain information on the type of I/M program, if any, in effect in the area being inventoried. The information required include:

year that the program was implemented;

stringency level;

whether or not a mechanics training program is included;

earliest and latest model year vehicles affected by the program currently; and

vehicle types affected.

This information can be obtained from the state agency responsible for the operation of the I/M program.

Finally, information is required concerning the average number of vehicle trips and average length of vehicle trips, by vehicle type. Default values are available within MOBILE2 and should be used unless local data are available for the study area.

The second set of data contains seven parameters describing the scenarios for which emission factors are to be calculated. The first element in this data set is the regional designation. The options are:

low altitude (less than 4000 feet above sea level), 49-state;

low altitude, California; and

high altitude (more than 4000 feet above sea level).

The second element is the specification of the calendar year for which the inventory is being developed. Currently, inventories must be developed to reflect weekday emissions during the peak pollutant months for:[8]

base year 1980, if possible; and

the proposed attainment year--1987.

This applies specifically to areas which are nonattainment for ozone. Otherwise, the calendar year(s) selected should be based on the overall intent of the inventory; if it is an annual update, the calendar year selected should be the inventory year.

Average travel speed data are required for the highway network. As presented in the previous section, speed data should reflect the average travel speed over the network rather than the free-flow speed only. If VMT by roadway functional category were developed, then separate emission factors for each roadway type will be calculated by specifying different speeds for each roadway type on separate MOBILE2 runs.

An ambient temperature representative of the peak pollutant season must also be specified. Typically, the average daily temperature during the peak season is specified.

The percentage of VMT occurring in the cold-start and hot-start mode for catalyst-equipped vehicles, and in the cold-start mode for non-catalyst vehicles must be estimated. For this particular application default values can be used in the absence of specific local data. If different roadway categories are used, separate values for each mode may be appropriate for each roadway category. For example, freeways may have a lower percentage of vehicles in the cold-start mode than do local roads.

Several additional parameters can be specified that will affect the emission factors derived by the MOBILE2 program. These involve specifying the extent to which automobile air conditioners are used (i.e., percentage of vehicles using air conditioners); the percentage of LDGV's, LDGT1's, and LDGT2's carrying extra 500 pound loads; and the percentage of LDGV's, LDGT1's, and LDGT2's that are towing trailers. In terms of air conditioner use, the basic decision is whether or not air conditioner use should be considered since the MOBILE2 model will compute the air conditioner useage based on the ambient temperature. The required inputs include the dry and wet bulb temperatures, as well as the absolute humidity in grains of water per pound of dry air.

For vehicle loading and trailer towing, the percentage of each type of light-duty vehicle carrying an extra load or towing a trailer must be specified. For purposes here, these corrections can be considered insignificant.

The data described above are then used as input to the MOBILE2 emission model, which computes an emission rate for each vehicle type, for each type of highway facility (actually, for each average speed value input). The emission factors are in grams of pollutant per mile. It is important to note that hydrocarbon emission factors can be computed as: (1) total hydrocarbons; (2) non-methane hydrocarbons; (3) separate evaporation and crankcase emission rates as well as the composite emission rate. In this regard the specific type of emission factor desired should be specified. The determination of whether total or non-methane hydrocarbon emissions should be computed ought to be based on the overall inventory design and specifications. If there is no real need to output evaporative and crankcase emission rates separately, only the composite hydrocarbons (either total or nonmethane component) emission factors should be specified.

Once the emission factors are available, they are multiplied by the appropriate activity factor to yield the highway source emissions for the pollutants carbon monoxide, hydrocarbons, and oxides of nitrogen.

For particulates and sulfur oxides, the emission factors are determined directly from the MOBILE2 User's Guide[2], and applied to the VMT by vehicle type to yield the emission estimates.

The method for developing estimates of future year emissions is identical, except the total county VMT figure is adjusted upward or downward, based on future year development estimates made by state or county planners. There is no practical method that could be discussed in the context of this document for independently projecting VMT. The process of developing an inventory of emissions from highway vehicles requires the expertise of state, regional, and county tranportation engineering and planning personnel.

4.4.4 INVENTORY MANAGEMENT

The basic requirements for documenting the procedures, sources of data, results, etc. are the same for highway vehicles as for other emission sources. The overall considerations in terms of inventory management are presented in Volume I of this series.[9]

4.5 METHOD 2--ESTIMATING EMISSIONS FOR URBAN AREAS USING PROCEDURES DEVELOPED BY FHWA

4.5.1 OVERVIEW AND SCOPE

Method 1 provides a procedure for developing or updating a highway source emission inventory for predominantly rural counties or small urban areas. Method 2 provides a similar procedure that is intended for use in developing and updating an inventory for those larger urbanized and standard and metropolitan statistical areas (SMSAs), under an agency's jurisdiction.

The basis for Method 2 is a procedure developed jointly by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation's Federal Highway Administration (FHWA). This method is described in detail in Reference 10 and is referred to as the Manual Method for Estimating Highway Emission Inventories.

This method follows the general process described for Method 1 (Figure 4-1). The primary differences between this method and Method 1 are in: (1) the techniques used to derive the activity factor--that is, the distributions of VMT by vehicle type for various highway speed categories; and (2) the emission computations. In this method, emissions are computed manually rather than with the MOBILE2 emissions model.

This method derives three activity factors that permit separate computation of:

Travel-related emissions,

Trip-related emissions, and

Vehicle-related emissions.

Travel-related emissions are a function of travel quantity (i.e., VMT) and are computed as the product of total VMT and a baseline emission factor. Trip-related emissions are a function of the number of vehicle trips that occur irrespective of the VMT. Finally, vehicle-related emissions are a function of the number of vehicles in the area and are associated with evaporative losses from the fuel system. Total emissions from the highway system are computed as the sum of these individual components.

The methods used for deriving activity factors for each component rely extensively on data developed by both Federal and state agencies to define the required travel characteristics. For example, previously established relationships between urban population size and VMT per capita are used to estimate total VMT based on current population. This method is not designed for accuracy and sensitivity. It should not be applied with the intent of using the results for detailed air quality modeling or for assessing the impact of emission control strategies. Further, this method applies to larger urbanized areas that usually have an ongoing regional transportation planning program. Therefore, consideration should be given to utilizing alternative methods, such as Methods 3 or 4 described later, that take advantage of the much more detailed transportation data usually available from transportation planning programs. If this general method is selected, locally developed data, where available, should be substituted for the more general relationships contained in Reference 10.

This method was developed for computing emission estimates manually; that is, without the use of MOBILE2. Since this was a primary objective in developing the method, the entire process of manually deriving emission estimates is presented here. Following the description of this method are instructions of how the basic elements of this method can be used to provide appropriate input for MOBILE2.

4.5.2 TOTALLY MANUAL METHOD FOR DERIVING EMISSION ESTIMATES

The intent of this section is to summarize the methods presented in Reference 10 for developing estimates of emissions from highway vehicles without the use of any formal computer models. Reference 10 contains numerous tables that are subject to periodic revision and, therefore, will not be presented here. If this manual method for developing an inventory of emissions from highway vehicles is to be used, the analyst should obtain a copy of Reference 10 and a determination made as to whether the tables contained therein are sufficiently up to date for the area being inventoried.

4.5.2.1 Derivation of Activity Factors

The first phase of the overall method is to develop activity factors, which, when applied to appropriate emission rates, yield estimates of the quantity of pollutant emissions produced by the region's highway network. To develop the activity factors, five data elements must be derived:

1. Regional or county vehicle population by vehicle type,
2. Total VMT,
3. VMT by vehicle type,
4. Speed characteristics for the highway network, and
5. Vehicle trip statistics.

Each of these is discussed below.

4.5.2.1.1 Estimating Regional Vehicle Population

Estimates of the regional auto and truck population for the study area are developed using per capita vehicle registration statistics and growth rates in vehicle ownership (vehicles per capita) developed by FHWA and presented in Reference 10 in Tables 8.1 and 8.2, respectively. Per capita auto and truck statistics for 1972 are presented for over 230 urbanized areas while the growth rates in autos and trucks per capita are presented for each state reflecting the period 1970 through 1975. These data, along with locally derived estimates of the study area population, are used to estimate total auto and truck populations, from:

$$\mathrm{AUTOS}_F = [1 + (\mathrm{YRS})(\mathrm{AGR}/100)]\ [(\mathrm{APC}_{72})(\mathrm{POP}_F)] \qquad (4\text{-}8)$$

and

$$\mathrm{TRUCKS}_F = [1 + (\mathrm{YRS})(\mathrm{TGR}/100)]\ [(\mathrm{TPC}_{72})(\mathrm{POP}_F)] \qquad (4\text{-}9)$$

where AUTOS_F = estimated auto population in the area for the inventory year F;

APC_{72} = autos per capita for 1972, from Table 8.1 in Reference 10;

TRUCKS_F = estimated truck population in the area for the inventory year F;

TPC_{72} = trucks per capita for 1972, from Table 8.1 in Reference 10;

YRS = number of years difference between the inventory year and 1972;

AGR = auto growth rate, from Table 8.2 in Reference 10;

TGR = truck growth rate, from Table 8.2 in Reference 10; and

POP_F = estimated population for the inventory year F.

The resulting values of AUTOS_F and TRUCKS_F are used to compute the vehicle-related emission component mentioned previously, which is associated with diurnal evaporative losses from the fuel system (for hydrocarbons only). Only two basic vehicle categories are of interest since Reference 10 provides evaporative emission factors that reflect a composite of the specific vehicle types included in the general auto and truck categories.

Alternative sources of regional auto and truck registration data should be considered. State motor vehicle registration agencies, for example, may be able to provide statistics on the regional vehicle population. Also, regional planning agencies may have more current information on per capita vehicle population than is presented in Reference 10.

4.5.2.1.2 Estimating Total Travel

Four methods are presented in Reference 10 for estimating total regional VMT. Prior to selecting a particular method, the availability and reliability of the data required for each method (and for alternative methods, such as those described in Method 1) should be assessed.

The first method presented in Reference 10 is to develop VMT estimates based on traffic counts taken in the region. It is very unlikely that sufficient counts would exist to develop VMT estimates for most areas. Therefore, special traffic counting studies would be required. In view of the overall scope and intent of Method 2, special data collection efforts (particularly of the type needed to develop estimates of regional VMT) are not recommended.

The second method presented in Reference 10 for estimating regional VMT is through the use of output data from travel simulation models. Most urban areas have continuing transportation planning programs that are responsible for assessing current and future transportation needs. These assessments are made with the aid of travel demand models that simulate various transportation parameters including current and future highway utilization. An output from these models is the total VMT accommodated by the existing or proposed regional highway system. The type of data available from the planning program varies from planning agency to planning agency, but, as a minimum, a base year VMT estimate for the planning network is typically available. It is important to recognize, however, that the transportaton planning base year may not be the same as the inventory base year, therefore the VMT estimates may require some adjustment. Also, the VMT estimates may only reflect interzonal travel, therefore a significant amount of local travel may not be included. In any case, if VMT estimates are developed from transportation planning data, the analyst must be certain that he/she is aware of exactly what the data represent. If adjustments are required, the transportation planning agency that developed the data should perform the adjustments.

The third method for estimating regional VMT involves the use of data compiled by FHWA regarding daily VMT per capita as a function of urban area population. Figure 8.1 in Reference 10 shows this relationship for the years 1977, 1982, and 1987. Population data must be derived locally.

The fourth method described in Reference 10 for estimating regional VMT is to use data compiled by individual state transportation departments and reported by FHWA in National Functional System Mileage and Travel Summary.[11] The data tabulated in this document represent daily VMT for each urbanized area in the U.S., estimated during 1975. The specific urban area boundaries assumed for these estimates may not be the actual ones that currently exist; therefore, some adjustment may be required. Also, basic travel patterns and trends may be somewhat different from those assumed when the VMT projections were made. The VMT data obtained from Reference 11 should, therefore, be reviewed and validated by the regional transportation agency prior to being used in the development of the emission inventory.

Finally, alternative methods for estimating regional VMT should be considered. The procedure described in Method 1 that uses VMT estimates from Highway Statistics[5] and an inventory of regional highway mileage by functional type would provide a good basis for assessing the reasonableness of VMT estimated using any of the four methods described above.

4.5.2.1.3 Distribution of VMT by Vehicle Type

The requirement as specified in Reference 10 is to disaggregate total VMT into two components--auto VMT and truck VMT. To accomplish this, Reference 10 provides a table (Table 8.4) indicating the percentages of total regional VMT performed by trucks for 34 different urban areas in the U.S. The percentages range from 10 to 21 percent and are based on several studies performed during the late 1960's and early 1970's. The recommended procedure is to select from the table one of the urban areas that is considered similar (population, geographic location, etc.) to the area being inventoried and use the corresponding truck factor. VMT by vehicle type is derived from:

$$VMT_T = VMT_{TOT} \times f_t \qquad (4\text{-}10)$$

and

$$VMT_A = VMT_{TOT} - VMT_T \qquad (4\text{-}11)$$

where VMT_T = truck VMT,

VMT_A = auto VMT,

VMT_{TOT} = total regional VMT, and

f_t = truck factor, from Table 8.4 in Reference 10.

4.5.2.1.4 Estimating Travel Speed

Since emission rates are a function of travel speed, estimates must be of the speed characteristics of the highway system must be developed. The guidance provided in Reference 10 is to use local data where they exist; otherwise use an average speed value of from 25 miles per hour for older, more densely developed urban areas to 35 miles per hour for more modern and smaller cities that have extensive freeway systems.

A more appropriate approach may be to disaggregate total VMT by functional roadway class and use actual speed study data, if available, or engineering estimates to characterize speed. This approach is explained in part of Method 1.

4.5.2.1.5 Estimating Trips

One component of the total emissions produced by highway vehicles is associated directly with the number of individual vehicle trips that occur. The procedures established in Reference 10 require that only auto trips be considered, since trip-related emissions have been incorporated into the truck emission rates applied to truck VMT.

The most appropriate method for determining the number of auto trips occurring in the study area is to use trip generation data, if available, from the regional transportation planning agency. If direct estimates of trips are not available, Reference 10 recommends the use of a set of curves that presents the relationship between average trip distance and the urban population for 1982 and 1987, and the application of the appropriate average trip distance to the auto VMT value derived in the previous step to yield total auto trips. The curves are presented in Figure 8.2 of Reference 10. The estimated number of auto trips occurring in the study area, then, is:

$$N = \frac{VMT_A}{ATD} \qquad (4\text{-}12)$$

where N = number of auto trips;

VMT_A = auto VMT, calculated from equation (4-11); and

ATD = average trip distance, derived from Figure 8.2 in Reference 10.

4.5.2.2 Calculation of Emissions

The data derived provide the basis for estimating total emissions from highway vehicles using emission factors from Reference 4. The procedures contained in Reference 10 for calculating each emission component - that is, vehicle-related, trip-related, and travel-related emissions are discussed below.

4.5.2.2.1 Calculating Vehicle-Related Emissions

Vehicle-related emissions are associated with evaporative losses from the fuel system and involve hydrocarbons only. They are calculated as the product of the regional vehicle population and an emission factor, which is presented in Reference 10 for calendar years 1977, 1982, and 1987. Evaporative losses are calculated separately for autos and trucks, as:

$$EVAP_A = AUTOS \times EF_{evapA} \quad (4\text{-}13)$$

and

$$EVAP_T = TRUCKS \times EF_{evapT} \quad (4\text{-}14)$$

where $EVAP_A$ = evaporative emissions from autos;

$EVAP_T$ = evaporative emissions from trucks;

AUTOS = number of autos in the study region, from equation (4-8);

TRUCKS = number of trucks in the study region, from equation (4-9);

EF_{evapA} = evaporative emission factor, in grams HC/day, for autos; from Reference 10; and

EF_{evapT} = evaporative emission factor, in grams HC/day, for trucks, from Reference 10.

4.5.2.2.2 Calculating Trip-Related Emissions

Trip-related emissions are calculated for autos only. These emissions are associated with the cold-start and hot-start conditions when the exhaust emissions rate is temporarily much higher than after the vehicle has been operated for a few minutes. Startup emissions are determined by the total number of auto trips, the percentage of those trips that start with the engine fully cooled, and the ambient temperature.

The first step in calculating trip-related emissions is to determine the number of trips that begin with the engine fully cooled to ambient temperature. Reference 10 provides two methods that require the use of regional parking duration data, and also provides a set of default values that can be applied in the absence of specific parking information. These default values are:

53 percent for calendar year 1977,

64 percent for calendar year 1982, and

67 percent for calendar year 1987.

The number of cold-start trips, then, is:

$$N_{cs} = N \times P_{cs} \quad (4\text{-}15)$$

where N_{cs} = number of trips in the cold-start mode;

N = total number of trips, from equation (4-12); and

P_{cs} = percentage of trips beginning in the cold-start mode, based on the percentages provided above, or local data.

Cold-start emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen are calculated separately as the product of the number of trips beginning in the cold-start mode and an emission factor provided from Table 8.6, 8.7, or 8.8 in Reference 10:

$$ECS_A = N_{cs} \times EF_{csA} \qquad (4\text{-}16)$$

where ECS_A = cold start emissions from auto trips;

N_{cs} = number of trips beginning in the cold-start mode, from equation (4-15); and

EF_{csA} = cold-start emission factor, in grams/trip, from Reference 10, Tables 8.6, 8.7, and 8.8, respectively for HC, CO, and NO_x emissions.

It should be noted that the cold-start emission factors for HC and CO are temperature dependent; therefore, these emission components are derived for a particular month or season. Again, the intent is generally to develop an inventory reflecting the critical season for the pollutant of interest. This usually means that HC inventories reflect summer conditions, while CO inventories are based on winter conditions. For NO_x emissions, a humidity correction factor incorporating ambient temperature, barometric pressure, and relative humidity must be applied. This correction factor is based on prevailing conditions during the morning hours (0700 to 0900 hours) during the critical NO_x season, and is computed as:

$$CF = 1.353 - \left[\frac{f\ R\ (T + 459.4)}{(6.449 \times 10^4)P - (4.887 \times 10^{-2})\ f\ R\ (T + 459.4)}\right] \qquad (4\text{-}17)$$

where CF = NO_x correction factor for humidity;

f = relative humidity expressed as a percent;

R = water vapor capacity in g/m^3, from Table 8.11 in Reference 10;

T = temperature in degrees F; and

P = barometric pressure in inches of Hg.

Compute CF and multiply the total NO_x emissions from all sources by CF to obtain the total NO_x corrected for humidity.

The second element of the trip-related emissions component concerns hot soak emissions. These are additional evaporative losses of HC that result from high engine temperatures at the end of a trip. Hot soak emissions are computed for autos only, from:

$$EHS_A = N \times EF_{hsA} \qquad (4\text{-}18)$$

where EHS_A = hot soak emissions from auto trips, HC only;

N = number of auto trips, from equation (4-12); and

EF_{hsA} = hot soak emission factor, in grams HC/trip, from page A8-18 of Reference 10.

4.5.2.2.3 Calculating Travel-Related Emissions

Travel-related emissions are computed as the product of VMT and an emission factor in grams of pollutant per VMT. Reference 10 provides emission factors for both autos and trucks, respectively, for HC, CO, and NO_x, as a function of average travel speed and calendar year, in Tables 8.8 and 8.9. Travel emissions for autos and trucks are computed from:

$$ETRA_A = \sum_{i=1}^{n} VMT_{Ai} \times EF_{traAi} \qquad (4\text{-}19)$$

$$ETRA_T = \sum_{i=1}^{n} VMT_{Ti} \times EF_{traTi} \qquad (4\text{-}20)$$

where $ETRA_A$ = travel emissions from autos;

VMT_{Ai} = VMT by autos at speed i;

EF_{traAi} = Emission factor, in grams of pollutant/VMT, at speed i, from Table 8.9 in Reference 10;

$ETRA_T$ = travel emissions from trucks;

VMT_{Ti} = VMT by trucks at speed i; and

EF_{traTi} = emission factor, in grams of pollutant/VMT, at speed i, from Table 8.10 in Reference 10.

4.5.2.2.4 Calculation of Total Emissions

Total emissions from highway vehicles in the inventory area are computed as the sum of the individual components:

For HC:

$$EHC = EVAP_A + EVAP_T + ECS_A + EHS_A + ETRA_A + ETRA_T \tag{4-21}$$

For CO:

$$ECO = ECS_A + ETRA_A + ETRA_T \tag{4-22}$$

And, for NO_x:

$$ENO_x = (CF) \times (ECS_A + ETRA_A + ETRA_T) \tag{4-23}$$

where EHC = total HC emissions from highway vehicles,

ECO = total CO emissions from highway vehicles,

ENO_x = total NO_x emissions from highway vehicles, and

all other terms are as defined previously.

4.5.3 ADAPTING THE MANUAL METHOD FOR USE WITH MOBILE2

The methods described above for deriving activity factors can also be applied where emission calculations are to be performed using MOBILE2 rather than a manual procedure. The activity factors are derived exactly as indicated in Section 4.5.2.1, with the exception that vehicle population and vehicle trip statistics do not have to be calculated. Otherwise, total VMT for the region is estimated as described in Section 4.5.2.1.2, and the distribution of the VMT by vehicle type is determined as in Section 4.5.2.1.3. Finally, the distribution of VMT by speed category is determined using the procedure discussed in Section 4.5.2.1.4, which completes the minimum requirements for activity factor specification.

Further disaggregation of VMT by vehicle categories--model year and type distributions--can be accomplished using default values in MOBILE2, as described in Section 4.4.2.4. Cold and hot start percentages should be obtained from the default values in the emission model (MOBILE2), rather than from the procedure described in Section 4.5.2.2.2 Other input, such as calendar year, meteorological parameters, etc., can be specified on the same basis as for the manual method of calculating emissions.

The manual method described in Reference 10 for calculating emissions is based on the MOBILE1 emission factors--MOBILE1 is the predecessor of MOBILE2. Thus, it is more appropriate to apply Method 2 herein (Section 4.5.2) whereby only the activity factors are derived using the procedures contained in Reference 10, and the emission computations are then performed using MOBILE2 emission factors.

4.6 METHOD 3--ESTIMATING EMISSIONS USING LINK-BASED TRANSPORTATION PLANNING DATA

Since the early 1960's, urban areas with populations over 50,000 have maintained formal transportation planning programs in order to meet Federal requirements for securing certain transportation funds. These programs are intended to establish the means for identifying both current and future transportation needs and for planning for the implementation of projects that will fulfill the defined needs. An important aspect of this process concerns the regional highway network. In order to assess the adequacy of the highway system, extensive effort is expended on carrying out detailed analyses of how the existing highway systems are utilized, and how they will be utilized in the future, given various scenarios for regional development. These analyses produce detailed quantitative characterizations of the highway network that allow the transportation analyst to determine what improvements are needed and how they should be sequenced. Of significance here is that these analyses also provide much of the information required for the derivation of emission estimates for the regional highway system. The objective of this section is to discuss how the data routinely developed by transportation planning agencies can be utilized to construct and maintain inventories of highway source emissions.

The method presented in this section and Method 2 presented in Section 4.5 are intended for use in estimating emissions from highway vehicles in the larger urbanized areas under an agency's jurisdiction (see Table 4-1). These emission estimates are then combined with estimates of rural areas to provide an inventory of highway vehicle emissions for the entire area under an agency's jurisdiction. However, if the data necessary for this method are available, this method can be used to estimate emissions from all areas (rural and urban) under the agency's jurisdiction.

4.6.1 OVERVIEW OF METHOD 3

Method 3 is referred to as a link-based approach since the primary focus is to define all vehicular activity in terms of travel over a system of individual highway links and calculate emissions based on the VMT and operating characteristics of traffic on each link. In this method, each vehicular emission component - that is, travel-related, trip-related, and vehicle-related component, is accounted for in a single emission factor, which is applied uniformly over the entire link. The overall concept is identical to that for Methods 1 and 2.

First, an activity factor is derived describing both the quantity of vehicular travel in terms of VMT, and the relevant operating conditions, such as travel speed, vehicle type mix, and hot and cold start percentages. Based on the operating characteristics, an emission factor is derived using the MOBILE2 emission model and applied to the travel quantity to yield total emissions. The primary difference between Method 3 and Methods 1 and 2 is that Method 3 permits the assessment of emissions at a much finer level.

Whereas Methods 1 and 2 develop emission estimates based on total network VMT or major system (expressways, arterials, minor arterials, etc.) VMT, and a single emission factor for the network or major system, Method 3 derives emission estimates based on specific VMT and emission factors for each of the hundreds of individual links that comprise the highway network. The advantage of Method 3 is that it has the capability of providing a more highly detailed assessment of emissions because of the much greater resolution of actual operating conditions throughout the entire highway network. This ability enables Method 3 to be used in air quality modeling and control strategy assessment as well as for basic inventory development. The disadvantage is that the entire process is more complicated than either Methods 1 or 2 and, therefore, requires a higher level of expertise.

4.6.2 OVERVIEW OF THE TRANSPORTATION PLANNING PROCESS

Since the transportation planning process plays a key role in this method, it is useful to discuss some of the fundamental concepts associated with that process. A basic requirement in the process of analyzing regional transportation characteristics is to develop an understanding of travel in terms of where travel activity occurs, what factors stimulate travel, and how the basic demand is satisfied.

The general methods and many of the models used by transportation planners are standard ones developed by the FHWA and the Urban Mass Transit Administration (UMTA) and included, respectively, in the PLANPAC/BACKPAC and UTPS computer program batteries. However, one who is not routinely involved with transportation planning and analysis is not likely to be required to directly utilize the models and data output therefrom without the assistance of a competent transportation planner. The intent here is to present the most basic concepts of transportation planning so that the air quality analyst who has no familiarity at all with the processes involved can begin to understand the relationships that exist between transportation and air quality planning activities. This will provide a starting point for the air quality analyst in terms of identifying procedures that can be applied in the development of a detailed emission inventory. It will not supplant the requirement for extensive involvement by transportation planning staff during the conduct of the inventory. The procedures and activities described in this overview are carried out by transportation planners and not by air quality personnel.

In studying travel, the region is divided into numerous areas called analysis zones. These analysis zones range in size from one block in the central business district (CBD) to several square miles in the less densely developed fringe areas. Zones are typically irregularly shaped, the boundaries often being streets, river banks, political or census boundaries, etc., but the intent is that each zone represent some more or less homogeneous land use pattern. The number of zones designated depends on the size and complexity of the planning region and may range from around 100 for smaller urban areas to several hundred for large urban areas. Several zones may be combined for different types of analyses to form analysis districts.

Once the analysis zones and districts are delineated, the highway network that will be used throughout the planning process is designated. This planning network consists primarily of the principal roadways in the region, usually limited to expressways, major and minor arterials, some collector-distributor streets, and a few local streets. The network is then divided into links by designating node points at intersections, analysis zone boundaries, political boundaries, river crossings, etc. Again, the number of individual links that result is a function of the size and complexity of the regional highway system. Some larger systems may contain over 1,000 links. The centroid of activity for each analysis zone is identified and is connected to the highway network by one or more pseudo-highway links called centroid connectors. The entire network is then analyzed to determine various characteristics of each link, such as current traffic volume carried (average daily traffic, or ADT), typical operating speed, capacity, number of lanes, lane width, whether curb parking is permitted, condition of the road surface, and others. These data, along with the node designations, link length, and various other information, are then used to form a record of each link. In the computer systems typically used, this file is called the Historical Record. A typical format for each link record is shown in Figure 4-2.

Detailed population, land use, and economic data are gathered for each analysis zone, and interviews may be conducted to determine the typical travel patterns of residents in each zone. The interviews attempt to tabulate, for each person residing at a particular location, the origin and destination of each trip; the time, purpose, and frequency of each trip; the travel mode used; and other similar data. Similar interviews are conducted of motorists entering the study area, although these focus primarily on identifying the origin, destination, and purpose of the particular trip being made when the interview is conducted. This entire data set is then analyzed to determine (1) the total number of trips produced in each analysis zone, by trip purpose; (2) the distribution of trips produced in each analysis zone to all other analysis zones (trip interchanges); (3) the distribution of trips by mode and purpose; and (4) the causal aspects of tripmaking. These analyses provide the basis for forecasting travel demand for future year development scenarios.*

The zone-to-zone travel demand, or trip distribution, is then input with the historical record to a traffic assignment model that distributes the auto trips over the highway network based on parameters such as travel speed, total

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*Many urban areas are now using disaggregate techniques to estimate travel demand. These techniques do not require the use of a zone system, but base travel demand on the household. Disaggregate techniques are more data-efficient than earlier techniques. Several disaggregate models are available in the UTPS package of computer programs.

Columns	Contents
1	Unused (perhaps identification)
2-6	a-node number
7	a-node leg number (0-3)
8-12	b-node number
13	b-node leg number (0-3)
14-17	Distance (XX.XX)
18	T or S for time or speed (a-b)
19-21	Time or speed (a-b) (X.XX/XX.X)
22-24	Turn penalty codes at node b
25-28	Hourly capacity (a-b)
29-31	Conversion factor (VPH/ADT)
32-36	Directional count (a-b)
37-38	Street width (a-b)
39	Parking (a-b)
40	Unused (a-b)
41	T or S for time or speed (b-a)
42-44	Time or speed (b-a) (X.XX/XX.X)
45-47	Turn penalty codes at node a
48-51	Hourly capacity (b-a)
52-54	Conversion factor (VPH/ADT)
55-59	Directional count (b-a)
60-61	Street width (b-a)
62	Parking (b-a)
63	Unused (b-a)
64	Administrative classification
65	Functional classification
66	Type facility
67	Surface type
68	Type area
69-70	Predominant land use
71-74	Link location
75-78	Route number
79	Condition
80	Unused

Source: Reference 12.

Figure 4-2. Link data contained in a Typical Historical Record File.

trip time, volume to capacity, etc. The traffic assignment model is typically run several times before a satisfactory distribution results. Each time it is run, comparisons are made between the total assigned volumes and actual measured volumes crossing a screenline, which usually cuts through several primary travel corridors. Satisfactory results are indicated when the total assigned and measured volumes are within approximately 10 percent of one another and the volumes assigned to individual links appear reasonable given the function that the link fulfills. The process is repeated with a new set of trip distribution parameters that reflect future year land use, population, and socioeconomic conditions. Also, new highway facilities may be added to the highway network. The result is an estimate of the base year and future travel demand on the regional highway system.

4.6.3 INVENTORY DEVELOPMENT

The basis for deriving activity factors for the regional highway network is data output from the transportation planning program. The first step in the entire highway vehicle inventory process is to determine exactly what data are available from the planning agency. Of concern at the early stages of inventory development is the calendar year or years represented in the existing planning data base. Typically, detailed highway systems analyses are performed for a base year and at least one horizon year, neither of which may match the desired inventory years. Base years currently tend to reflect 1977 through 1979, while horizon years of 1990, 1995, and 2000 are commonly used. A decision must be made regarding the methods to be used to develop data reflecting the desired inventory base year if it is different from the transportation planning base or horizon year. The decision may be to simply adjust the transportation planning data to suit the inventory requirements by interpolation, or to regenerate the highway network data from new trip generation, distribution, and traffic assignment modeling runs. If the inventory results are to be used to perform detailed air quality modeling and to assess the impacts of mobile source emission control measures, consideration should be given to regenerating the required data in its entirety. On the other hand, if the inventory is not to be used for these purposes, it is more practical to interpolate between the base year and the horizon year to obtain data for the desired inventory base year.

The next requirement is to determine how the transportation planning data are to be translated to emission estimates. Since the historical record essentially provides the necessary travel data, it could be used to manually tabulate the travel characteristics of each link. Many urban areas have developed their own emission calculation computer programs based on MOBILE1 or MOBILE2, and have interfaced the programs with their transportation planning models. There are several computer models available that are designed to directly interface with the PLANPAC/BACKPAC and UTPS models to produce emission estimates or to produce aggregations of individual highway link data, which are then used as input to an appropriate emission model; four of these are described below.

4.6.3.1 HWYEMIS1

The first of these models is called HWYEMIS1, which was developed by and is available from the FHWA.[13] Input required consists of:

- Historical record containing
  - Network description
  - Link speed
  - Average daily traffic (ADT) volume on each link
  - Area type
  - Predominant land use
  - Functional classification
- Time interval of the analysis
- Percentage of ADT occuring during each time interval
- Other input required by the emission model
  - Vehicle age distribution
  - Vehicle type distribution
  - Percentage of cold and hot starts
  - Ambient temperature
  - Others as discussed previously (Section 4.4.3)

HWYEMIS1 uses the historical record and other input to derive an emission factor for each link, and applies this factor to the product of the link length and the ADT for each time interval to yield link emissions. The model varies cold and hot start percentages as a function of both time of day and location (i.e., CBD, residential area, commercial location). If various data elements such as vehicle age distribution or vehicle type distribution are not directly input, default values are assigned by the emission model. HWYEMIS1 produces a link-by-link file of emissions for each time interval. An additional computer routine from the PLANPAC/BACKPAC battery called SAPLSM can be linked to the HWYEMIS1 program to produce tabulations of emissions within grid cells. This type of output is necessary for most air quality modeling efforts.

Nonnetwork VMT are not included in the historical record. Therefore, a method must be developed for accounting for this additional travel.

Nonnetwork VMT reflects intrazonal trips. The VMT associated with these trips is estimated as the product of the number of intrazonal trips occurring in the analysis zone, and one-half the radius of the analysis zone as measured along major travel routes (alternatively, the length of the centroid connector may be used). If gridded emission output is required, the nonnetwork VMT should be assigned to specific links.

The MOBILE1 emission model is currently included in the HWYEMIS1 program. MOBILE1 has been superceded by MOBILE2, therefore, the HWYEMIS1 program should be modified by substituting emission models before applying it to the emission inventory effort. Since MOBILE1 and MOBILE2 are compatible the substitution is not difficult.

4.6.3.2 APRAC-2

The second computer model that can be used to calculate emissions is APRAC-2,[14] which is available through the U.S. Environmental Protection Agency. Input required by APRAC-2 is similar to that for HWYEMIS1. APRAC-2 can, however, compute link speeds based on volume-to-capacity ratios (V/C), when capacity is input, or the speed parameter specified in the historical record can be used. APRAC-2 accounts for non-network VMT either as a constant percentage of network VMT, or as a variable percentage based on the general locale. If traffic volumes contained in the historical record represent average annual daily traffic (AADT), a seasonal adjustment factor must be provided. This model is also capable of responding in detail to variations in both total link volume and directional volumes as a function of time of day. This capability requires detailed input concerning the hourly traffic patterns by general locale.

APRAC-2 has been updated several times since it was originally introduced in 1977. The more recent editions contain the MOBILE1 emission model, whereas the earlier ones included emission factors from Supplement 5 of AP-42.[3] The emission model should be updated by substituting MOBILE2 before it is used.

4.6.3.3 Other Transportation Models

Two additional computer models are available that can be used in the development of regional emission inventories. The basic difference between these and the two models described above, however, is that these models are not really link-based ones. They do provide the capability of using regional transportation planning data to generate emission estimates at various subsets of the region.

The first of these models is the Community Aggregate Planning Model,[15] or CAPM, which is a sketch planning model contained in the UTPS battery. CAPM is used to calculate auto and truck travel (VMT) and speeds for an entire region, for different settings (e.g., CBD, commercial areas, residential areas, etc.), or for "communities," which are areas that are approximately the size of analysis districts. Input to CAPM includes trip generation and trip distribution data, and area, predominant land use, and lane-miles of arterial roadways (including expressways) in each community or locale. The model generates VMT and speed data for each subarea or roadway system (either arterials or expressways), by time of day. The output data are then used as the basic activity factors for each area or highway system, and are input into the MOBILE2 model along with other requisite data (i.e., cold and hot start data, ambient temperature, distribution of VMT by vehicle type and vehicle age, etc.) to derive the emission estimates.

The second model is an outgrowth of the CAPM model and is referred to as the Regional Highway Emissions Model (RHEM).[16] RHEM computes the total regional VMT, and then distributes this VMT to various functional roadway categories, by hour of the day, and generates a corresponding estimate of average travel speed. The input required includes:

Regional auto trips

Regional truck trips

Travel time for work trips

Area of region

Auto trips through the region

Truck trips through the region

Lane miles of freeways

Lane miles of surface arterials

Trip and travel time data are available from trip generation and distribution analyses, and from the historical record. Other sources, such as street inventories and area base maps may also be required.

As with the CAPM model, the output from RHEM is used as input to the MOBILE2 emission model to derive estimates of highway source emissions.

4.7 METHOD 4--ESTIMATING EMISSIONS USING A HYBRID MODELING APPROACH

This method is a modification of Method 3. Essentially, the concept involved is that a higher degree of accuracy can be obtained in the inventorying process if the three vehicular emission components--that is, vehicle related, travel related, and trip related components--are considered separately. No formal methods are currently documented for performing this type of analysis, therefore, the intent here is to present basic concepts rather than actual methods.

It can be expected that this method will be much more data intensive than any of the other methods. A logical starting point in determining whether it should be applied in a given area is to assess the quality and quantity of existing transportation planning data. Specifically, this method requires that detailed trip data be available so that both the number and types of trip productions and attractions can be determined. It is expected that this hybrid approach would require supplementary data collection in some applications, and additional data analysis in all instances.

4.7.1 OVERVIEW OF METHOD 4

In this method, detailed transportation planning data are used to develop estimates of highway source emissions by individual emission component. The results obtained using this hybrid approach will provide a higher degree of resolution in the overall inventory in terms of both time and space. This method is most appropriate where it is expected that the results will be used for detailed air quality modeling and control strategy assessment.

As indicated, this method differs from Method 3 in that each emission component is considered separately using different analytical techniques. Travel related emissions are estimated using either HWYEMIS1, APRAC-2, or some other appropriate technique as described in Method 3. Trip-end emissions associated with cold and hot starts, and with hot-soak emissions, are assessed based on the detailed analysis of trip productions and attractions for each analysis zone. Finally, vehicle related emissions associated with evaporative losses due to changes in ambient temperature over the course of a day, are analyzed using essentially the same data as are used in estimating trip-related emissions.

The basic emission model used is MOBILE2. With this hybrid approach, there is currently no standard program that allows direct computer processing of the trip and vehicle related emission components. These must be calculated manually, or special computer programs prepared for integrating the trip characterizations with the appropriate MOBILE2 emission factors.

4.7.2 ESTIMATING TRAVEL RELATED EMISSIONS

Since the overall method is intended to provide a high degree of resolution in the inventory, it can be assumed here that a gridded emission output is required. The travel component of the inventory can be conveniently handled using either the HWYEMIS1 or APRAC-2 models described above. The only difference here is that the input data will indicate that no cold or hot starts are occurring on any of the links. Also, the ICEVFG parameter in the MOBILE2 program must be either a 2 or 3, which then requires the user to specify the number of trips per day and the mileage per trip parameters normally used to calculate the vehicle and trip related emission components. The values input for the trips per day and miles per trip parameters will be 0, resulting in MOBILE2 computing an emission factor for each link that reflects only travel related emissions.

4.7.3 ESTIMATING TRIP RELATED EMISSIONS

For the analysis of hydrocarbon emissions, two separate components are associated with trip emissions. The first component includes hot-soak emissions, which result from evaporation of fuel in the carburetor and intake system after the engine has been shut off. These losses tend to occur during the first hour after the engine has been shut off, but it is likely that the greatest quantity of these emissions are produced during the first several minutes after shutdown. To derive an estimate of the hot soak emissions produced in an analysis zone, the number of auto driver trips (both interzonal and intrazonal) associated with the zone must be determined. The trip tables generally available will merely indicate the total trip attractions to each zone on a daily basis, therefore, if an hourly distribution is desired, some further analysis is required. If the trip record files are available, a special computer analysis can be made to define the arrival time distribution of trips by destination. Alternatively, the entire regional trip data set can be analyzed by purpose and time of occurrence to identify general time distributions, which can then be applied to each zone. Once an estimate of the number of trips terminating in each zone during each hour has been derived, an emission factor, in grams per trip, can be applied to yield total emissions per hour per zone.

The second component of the trip related emissions applies to hydrocarbons, as well as carbon monoxide and oxides of nitrogen. This is the cold- and hot-start emissions increment. This component can be analyzed in any of several ways. The most straightforward of these methods is to use the empirical methods developed by Ellis for the FHWA[17] that consider cold and hot starts to be a function of trip purpose and locale. Because of significant variations in travel among urban areas, local data should be used when applying this method. The specific methods are described in detail in Reference 17. A major concern in applying this method is the age of the travel data. If the data are more than 5 years old, and the area has been growing, travel patterns may have changed and the cold and hot start percentages may no longer be valid. Alternatively, hourly trip data can be assessed on an analysis district basis to identify the number of trips beginning each hour as a function of the parking duration prior to beginning the trip. Note that the larger the analysis zone, the less spatial resolution will be reflected in the emission inventory. The minimum parking duration that will cause a cold start to occur depends on the model year of the vehicle--for pre-1975 vehicles, which did not have catalytic converters, the cold soak time required to produce a cold start is about 4 hours, whereas for a post-1974 vehicle with a catalytic converter, the minimum soak time is 1 hour. The relative percentages of catalytic and noncatalytic vehicles changes over time. Therefore, the cold start distribution will also change (cold start precentages are increasing). Once the cold start percentages for the analysis district have been identified, they can be applied to the individual analysis zones contained in the district to determine the number of trips beginning in the cold mode. To calculate the cold start emissions, an emission factor and a VMT quantity must be derived. To calculate the emission factor, a value for travel speed must be designated. This value can be the approximate average speed for all travel in the analysis zone. In terms of VMT per trip, the product of the average trip speed and the travel time in the cold mode (based on Reference 18, a value of 200 seconds is recommended) will yield VMT. An assumption that can be made, which simplifies the analysis, is that the entire cold-start increment occurs in the zone where the trip originates. This cold-start VMT must be removed from the VMT calculated under Travel Related Emissions (Section 4.7.2) for each zone to avoid double counting. If it is desired to assign the cold-start emissions to specific links, References 17 and 18 should be consulted to determine which types of links in various locales are most likely to be carrying vehicles operating in the cold-start mode during different time periods.

4.7.4 ESTIMATING VEHICLE RELATED EMISSIONS

Vehicle related emissions result from the expansion of fuel vapor in the fuel tank, due to the increase in ambient temperature during the day. The MOBILE2 evaporative emission factor for hydrocarbons includes these emissions, but a more detailed inventory may be desired. No formal procedure exists for preparing such an inventory, but emission estimates are possible. Given the cause of these emissions, it can be assumed that diurnal emissions are likely to occur between the hours of 6 a.m. and 6 p.m. A detailed assessment of these emissions could be made by determining the average number of vehicles in each analysis zone hourly during this time period. This number will already have been determined during the estimation of trip related emissions (Section 4.7.3). An appropriate emission factor is then applied to each hourly zonal total. Reference 10 contains evaporative emission factors for cars and trucks on a grams per day basis. If these factors are applied on an hourly basis and under the assumption that the emissions actually occur during only 12 hours of the day, the hourly rate would be equal to one-twelfth of the daily rate as specified in Reference 10.

4.7.5 TOTAL EMISSIONS

The total emissions are the sum of the individual components. The travel related and trip related components can be described in terms of link emissions, whereas the vehicle related component is considered on an areawide basis. If a gridded emission format is used, the vehicle related emissions will have to be assigned to individual grids using a manual method that considers the area of the analysis zone contained in the grid cell. The travel and trip related emissions can be handled by the previously mentioned gridding programs since, again, these are primarily link emissions.

References for Chapter 4.0

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17. Determination of Vehicular Cold and Hot Operating Fractions for Estimating Highway Emissions, U.S. Department of Transportation, Federal Highway Administration, Washington, DC, September 1978.

18. Determination of Percentages of Vehicles Operating in the Cold-Start Mode, EPA-450/3-77-028, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1978.

5.0 EMISSIONS FROM AIRCRAFT

Pollutants are emitted from aircraft whenever the engines are operating. In the context of emission inventory development, however, the concern is limited to those portions of the flight that occur between ground level and an altitude defined as the above ground level inversion height. Within this layer, the air is fairly stable and aerosol emissions tend to diffuse rather than be transported away. As a result, emissions occurring below the ground level inversion height have an affect on air quality at ground level, owing to the mixing that occurs within the air cell.

Emission characteristics vary as a function of both the type of aircraft and the operating mode. Aircraft can be categorized broadly as either civil or military. Civil aircraft include all categories of fixed and rotary wing craft from the smallest single engine, privately owned and operated, to the largest commercial aircraft. Within the civil category, two subcategories are often discussed--commercial, and general. Commercial aircraft are used in regularly scheduled flights, while general aviation includes all nonmilitary aircraft not used in scheduled service. In the development of emission inventories, it is necessary to account for specific types of aircraft using each airfield.

Aircraft emissions are affected by the throttle power setting--that is, the percentage of maximum power that the engines are producing at a given time. However, the power setting is fairly predictable based on the specific operating mode in which the aircraft is operating. For purposes of the inventory development, five operating modes are of interest:

Approach,

Taxi/idle in,

Taxi/idle out,

Takeoff, and

Climb out.

Collectively, these five modes form the Landing-Takeoff (LTO) cycle, which provides a basis for allocating aircraft emissions to a specific region.

The development of a complete emission inventory for a region requires that an accounting be made of all emission sources, including aircraft. The objective of this section is to delineate methods that can be used to prepare and maintain an inventory of emissions from aircraft, as part of a comprehensive inventorying program.

5.1 OVERVIEW OF INVENTORY METHODS

Emissions from aircraft are estimated using a set of activity factors, that reflect the specific type of aircraft and their operating characteristics, and emission factors, developed by the U.S. Environmental Protection Agency (EPA) which are reported in Compilation of Air Pollutant Emission Factors,[1] hereafter referred to as AP-42. The activity factors are developed for individual types of aircraft owing to the wide variation in emission characteristics associated with each type. A listing of the specific types of aircraft, currently in service, in each category is shown in Tables 5-1 and 5-2.

Activity factors describe the time spent in each of the five operating modes (i.e., approach, taxi/idle in, taxi/idle out, takeoff, and climb out) as the aircraft completes a Landing-Takeoff (LTO) cycle. Emission factors for each type of aircraft have been developed in terms of emissions produced per hour of operation in each of the five operating modes. Therefore, the product of the activity factor and the emission factor is the quantity of emissions produced.

In terms of developing estimates of emissions from aircraft, the largest effort is in the derivation of the activity factors. The principal airports handling commercial and general aircraft are required by the Federal Aviation Administration to maintain detailed records of both the number and types of aircraft using the facility. Therefore, a data base can be established without much difficulty. It is more difficult to obtain similar information for military airfields since the data may have some security classification that would prohibit its release. However, military facilities are required to report emissions to the regional EPA office in whose jurisdiction they are located.

Two methods can be applied to derive emission estimates. The first involves the application of emission rates that reflect a generalized Time-In-Mode (TIM) scenario for each LTO cycle, for each type of aircraft. The required activity factor for this method is simply the number of LTO cycles for each type of aircraft. A more detailed analysis that considers more specifically the actual TIM for each airport facility can be performed. For this more detailed method, the activity factor is the actual TIM for each of the five modes that comprise the LTO cycle, for each type of aircraft. Both methods are described in detail in the following sections.

5.2 METHOD 1--USE OF A GENERALIZED TIME-IN-MODE SCENARIO TO ESTIMATE EMISSIONS

This method provides a relatively quick indication of the emissions produced by aircraft operations in an area. It is, however, based largely on a set of simplifying assumptions that limit the accuracy.

The method involves derivation of a set of activity factors, which define the number of each type of aircraft using each airport facility. Once the activity factors have been defined, an emission factor for the type of

TABLE 5-1. CIVIL AIRCRAFT CATEGORIES USED IN EMISSION INVENTORY DEVELOPMENT

Aircraft	Engine			
	No.	Mfg.	Type	Model/Series
Supersonic transport				
BAC/Aerospatiale Concorde	4	RR	TF	Olymp. 593-610
Short, medium, long range and jumbo jets				
BAC 111-400	2	RR	TF	Spey 511
Boeing 707-320B	4	P&W	TF	JT3D-7
Boeing 727-200	3	P&W	TF	JT8D-17
Boeing 737-200	2	P&W	TF	JT8D-17
Boeing 747-200B	4	P&W	TF	JT9D-7
Boeing 747-200B	4	P&W	TF	JT9D-70
Boeing 747-200B	4	RR	TF	RB211-524
Lockheed L1011-200	3	RR	TF	RB211-524
Lockheed L1011-100	3	RR	TF	RB211-22B
McDonnell-Douglas DC8-63	4	P&W	TF	JT3D-7
McDonnell-Douglas DC9-50	2	P&W	TF	JT8D-17
McDonnell-Douglas DC10-30	3	GE	TF	CF6-50C
Air carrier turboprops - commuter, feeder line and freighters				
Beech 99	2	PWC	TP	PT6A-28
GD/Convair 580	2	All	TP	501
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Fairchild F27 and FH227	2	RR	TP	R. Da. 7
Grumman Goose	2	PWC	TP	PT6A-27
Lockheed L188 Electra	4	All	TP	501
Lockhead L100 Hercules	4	All	TP	501
Swearingen Metro-2	2	GA	TP	TPE 331-3
Business jets				
Cessna Citation	2	P&W	TF	JT15D-1
Dassault Falcon 20	2	GE	TF	CF700-2D
Gates Learjet 24D	2	GE	TJ	CJ610-6
Gates Learjet 35, 36	2	GE	TF	TPE 731-2
Rockwell International Shoreliner 75A	2	GE	TF	CF 700
Business turboprops (EPA Class P2)				
Beech B99 Airliner	2	PWC	TP	PT6A-27
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Shorts Skyvan-3	2	GA	TP	TPE-331-2
Swearingen Merlin IIIA	2	GA	TP	TPE-331-3
General aviation piston (EPA Class P1)				
Cessna 150	1	Con	O	O-200
Piper Warrior	1	Lyc	O	O-320
Cessna Pressurized Skymaster	2	Con	O	TSIO-360C
Piper Navajo Chieftain	2	Lyn	O	TIO-540

Source: Reference 1, p. 3.2.1-3.

Note: This table is presented for illustrative purposes and therefore is not intended to provide a comprehensive listing of all types of aircraft that are in use, currently. For additional details and an explanation of abbreviations, see Section 3.2.1 of AP-42.[1]

TABLE 5-2. MILITARY AIRCRAFT CATEGORIES USED IN EMISSION INVENTORY DEVELOPMENT.

Aircraft mission (Class)	DOD Designation	Popular name	Manufacturer	Service	Power plant		
					No. & Type	Mfg.	Designation
Combat	A-4	Skyhawk	McD-Doug	USN, USMC	1 TJ	P&W	J52, J65
	A-7	Corsair 2	Vought	USN	1 TF	All, P&W	TF41, TF30
	F-4	Phantom 2	McD-Doug	USAF, USN	2 TJ	GE	J79
	F-5	Freedom Fighter/ Tiger 2	Northrop	USAF	2 TJ	GE	J85
	F-14	Tomcat	Grumman	USN	2 TF	P&W	TF30, F401
	F-15A	Eagle	McD-Doug	USAF	2 TF	P&W	F100
	F-16	-	GD/FW	USAF	1 TF	P&W	F100
Bomber	B-52	Stratofortress	Boeing	USAF	8 TJ, TF	P&W	J57, TF33
Transport Patrol/Antisub	C-5A	Galaxy	GELAC	USAF	4 TF	GE	TF39
	C-130	Hercules	GELAC	USAF, USN, USCG	4 TP	All	T56
	KC-135	Stratotanker	Boeing	USAF	4 TJ	P&W	J57
	C-141	Starlifter	GELAC	USAF	4 TF	P&W	TF33
	P-3C	Orion	CALAC	USN	4 TP	All	T56
	S-3A	Viking	CALAC	USN	2 TF	GE	TF34
Trainer	T-34C	Turbo Mentor	Beech	USN	1 TP	PWC	PT6A
	T-38	Talon	Northrop	USAF	2 TJ	GE	J85
Helicopter	UH-1H	Iroquois/Huey	Bell	USA, USN	1 TS	Lyc, GE	T53, T58
	HH-3	Sea King/Jolly Green Giant	Sikorsky	USAF, USN, USCG	2 TS	GE	T58
	CH-47	Chinook	Boeing Vertol	USA	2 TS	Lyc	T55

Source: Reference 1, p. 3.2.1-4.

Note: This table is presented for illustrative purposes and therefore is not intended to provide a comprehensive listing of all types of aircraft that are in use, currently. For additional details and an explanation of abbreviations, see Section 3.2.1 of AP-42.[1]

aircraft is applied, which yields an estimate of the quantity of emissions produced. The two steps--derivation of the activity factor, and calculation of emissions--are discussed in the following sub-sections.

5.2.1 DERIVATION OF AN ACTIVITY FACTOR

The primary requirements in order to derive the activity factor are a listing of the number of LTO cycles occurring at each airport facility, by type of aircraft. The first step in this process is to identify all airports, including privately owned, publicly owned, and military. Private air strips typically do not warrant consideration owing to the relatively low level of activity associated with their operation. The source of this information is likely to be the analyst's familiarity with the area being inventoried; although other sources such as maps and directories can also be used. References 2 and 3 provide a list of airports with Federal Aviation Administration (FAA) control towers, which are the most active civil airports, for each state.

After identifying airports, the next step is to determine the number of LTO cycles that occurred during the inventory year, by aircraft type. For commercial aircraft, this information can be obtained directly from Table 7 of Reference 3, which lists total departures by aircraft type for each airport in the U.S. where scheduled service is available. This Reference is published annually and provides total annual statistics; it is usually published during the fall of the year subsequent to the reporting year. An excerpt from Table 7 of Reference 3 is presented here in Figure 5-1, to indicate the type and format of data contained therein. For general aviation activity, Reference 2 should be consulted. Table 4 of Reference 2 (an excerpt from which is shown here in Figure 5-2, for illustrative purposes) shows itinerant, local, and total operations* by air carrier, air taxi, general aviation, and military aircraft, for each airport in the U.S. that has an FAA-operated control tower. Each operation accounted for in the table represents one landing or one takeoff, therefore the total operations divided by 2 equals the number of LTO cycles. For this method, further disaggregation of general aviation aircraft is not warranted. If the desired inventory year is different (more recent) from the year represented by the most current editions of References 2 and 3, adjustments can be made by obtaining as much data for the desired year as is available, and using it to provide a basis for estimating the relative level of activity between the two years. This requires direct interviews with airport officials to obtain the necessary data. The adjustment factor is:

$$f = \sum_{i=1}^{n} O_{ij} \Big/ \sum_{i=1}^{n} O_{ik} \qquad (5\text{-}1)$$

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*Itinerant operations refer to flights that leave from or originate away from the general area of the airport (beyond 20 miles radius), while local flights occur entirely within a 20-mile radius of the airport, although the origin or destination may not be at the airport. It should be noted that military airfields are not included in this table.

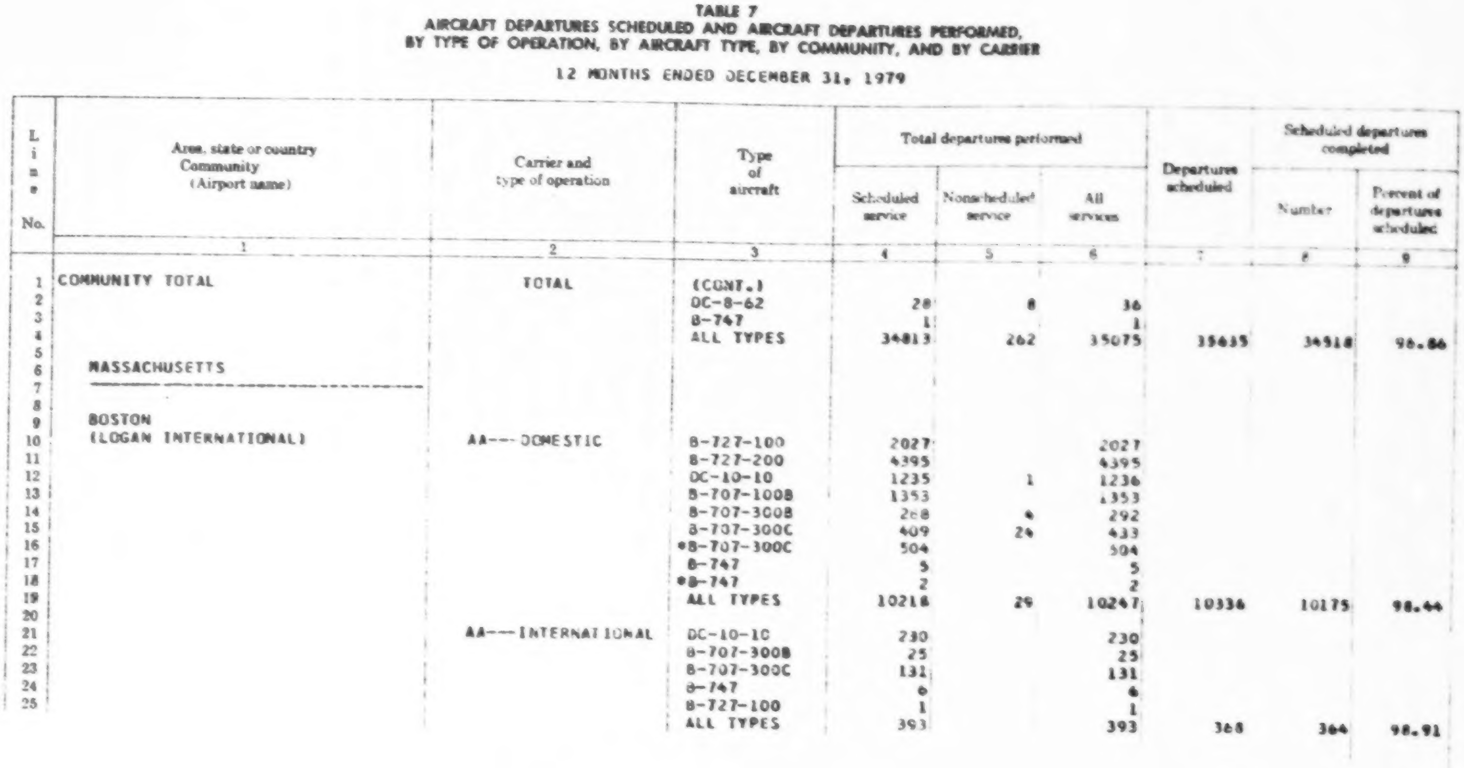

TABLE 7
AIRCRAFT DEPARTURES SCHEDULED AND AIRCRAFT DEPARTURES PERFORMED,
BY TYPE OF OPERATION, BY AIRCRAFT TYPE, BY COMMUNITY, AND BY CARRIER

12 MONTHS ENDED DECEMBER 31, 1979

Line No.	Area, state or country Community (Airport name)	Carrier and type of operation	Type of aircraft	Total departures performed			Departures scheduled	Scheduled departures completed	
				Scheduled service	Nonscheduled service	All services		Number	Percent of departures scheduled
	1	2	3	4	5	6	7	8	9
1	COMMUNITY TOTAL	TOTAL	(CONT.)						
2			DC-8-62	28	8	36			
3			B-747	1		1			
4			ALL TYPES	34813	262	35075	35635	34518	96.86
5									
6	MASSACHUSETTS								
7									
8									
9	BOSTON								
10	(LOGAN INTERNATIONAL)	AA---DOMESTIC	B-727-100	2027		2027			
11			B-727-200	4395		4395			
12			DC-10-10	1235	1	1236			
13			B-707-100B	1353		1353			
14			B-707-300B	288	4	292			
15			B-707-300C	409	24	433			
16			*B-707-300C	504		504			
17			B-747	5		5			
18			*B-747	2		2			
19			ALL TYPES	10218	29	10247	10336	10175	98.44
20									
21		AA---INTERNATIONAL	DC-10-10	230		230			
22			B-707-300B	25		25			
23			B-707-300C	131		131			
24			B-747	6		6			
25			B-727-100	1		1			
			ALL TYPES	393		393	368	364	98.91

Figure 5-1. Excerpt from Table 7 of Reference 3 showing airport activity by aircraft type.

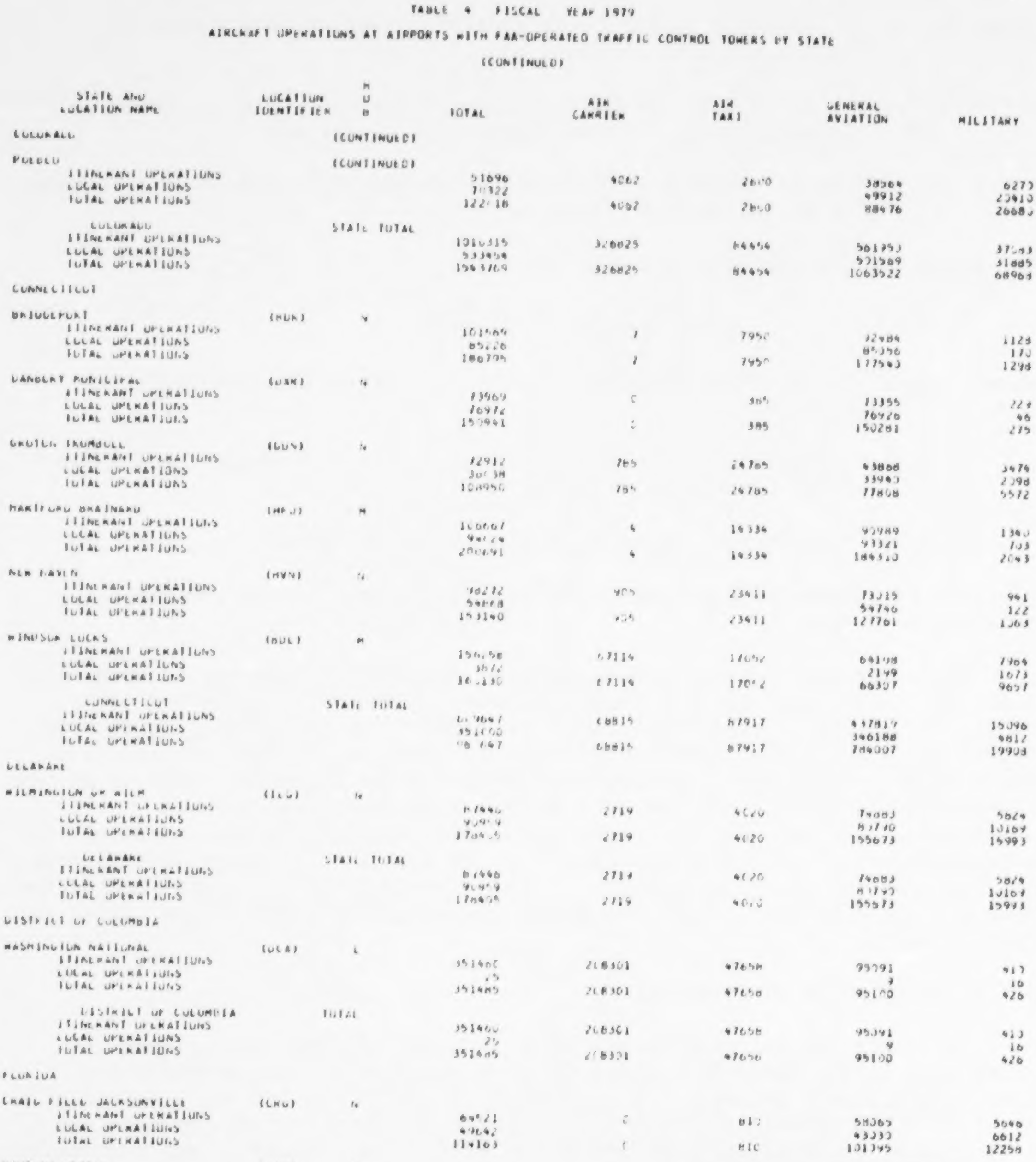

TABLE 4 FISCAL YEAR 1979

AIRCRAFT OPERATIONS AT AIRPORTS WITH FAA-OPERATED TRAFFIC CONTROL TOWERS BY STATE

(CONTINUED)

STATE AND LOCATION NAME	LOCATION IDENTIFIER	HUB	TOTAL	AIR CARRIER	AIR TAXI	GENERAL AVIATION	MILITARY
COLORADO	(CONTINUED)						
PUEBLO	(CONTINUED)						
ITINERANT OPERATIONS			51696	4062	2600	38564	6273
LOCAL OPERATIONS			70322			49912	20410
TOTAL OPERATIONS			122018	4062	2600	88476	26683
COLORADO	STATE TOTAL						
ITINERANT OPERATIONS			1010315	326825	84454	561953	37083
LOCAL OPERATIONS			533454			501569	31885
TOTAL OPERATIONS			1543769	326825	84454	1063522	68968
CONNECTICUT							
BRIDGEPORT	(BDR)	N					
ITINERANT OPERATIONS			101569	7	7950	92484	1128
LOCAL OPERATIONS			85226			85056	170
TOTAL OPERATIONS			186795	7	7950	177540	1298
DANBURY MUNICIPAL	(DXR)	N					
ITINERANT OPERATIONS			73969	0	385	73355	229
LOCAL OPERATIONS			76972			76926	46
TOTAL OPERATIONS			150941	0	385	150281	275
GROTON TRUMBULL	(GON)	N					
ITINERANT OPERATIONS			72912	785	24785	43868	3474
LOCAL OPERATIONS			36038			33940	2098
TOTAL OPERATIONS			108950	785	24785	77808	5572
HARTFORD BRAINARD	(HFD)	M					
ITINERANT OPERATIONS			106667	4	14334	90989	1340
LOCAL OPERATIONS			94024			93321	703
TOTAL OPERATIONS			200691	4	14334	184310	2043
NEW HAVEN	(HVN)	N					
ITINERANT OPERATIONS			98272	905	23411	73015	941
LOCAL OPERATIONS			54868			54746	122
TOTAL OPERATIONS			153140	905	23411	127761	1063
WINDSOR LOCKS	(BDL)	M					
ITINERANT OPERATIONS			156258	67114	17052	64108	7984
LOCAL OPERATIONS			3872			2199	1673
TOTAL OPERATIONS			160130	67114	17052	66307	9657
CONNECTICUT	STATE TOTAL						
ITINERANT OPERATIONS			609647	68815	87917	437819	15096
LOCAL OPERATIONS			351000			346188	4812
TOTAL OPERATIONS			960647	68815	87917	784007	19908
DELAWARE							
WILMINGTON GR WILM	(ILG)	N					
ITINERANT OPERATIONS			87446	2719	4020	74883	5824
LOCAL OPERATIONS			90959			80790	10169
TOTAL OPERATIONS			178405	2719	4020	155673	15993
DELAWARE	STATE TOTAL						
ITINERANT OPERATIONS			87446	2719	4020	74883	5824
LOCAL OPERATIONS			90959			80790	10169
TOTAL OPERATIONS			178405	2719	4020	155673	15993
DISTRICT OF COLUMBIA							
WASHINGTON NATIONAL	(DCA)	L					
ITINERANT OPERATIONS			351460	208301	47658	95091	410
LOCAL OPERATIONS			25			9	16
TOTAL OPERATIONS			351485	208301	47658	95100	426
DISTRICT OF COLUMBIA	TOTAL						
ITINERANT OPERATIONS			351460	208301	47658	95091	410
LOCAL OPERATIONS			25			9	16
TOTAL OPERATIONS			351485	208301	47658	95100	426
FLORIDA							
CRAIG FIELD JACKSONVILLE	(CRG)	N					
ITINERANT OPERATIONS			64521	0	810	58065	5646
LOCAL OPERATIONS			49642			43030	6612
TOTAL OPERATIONS			114163	0	810	101095	12258
DAYTONA BEACH	(DAB)	S					

Reproduced from best available copy.

Figure 5-2. Excerpt of Table 4 from Reference 2 showing airport activity by aviation category.

where f = adjustment factor to be applied to adjust year k data to reflect inventory year j;

O_{ij} = total operations for n months of inventory year j, based on data obtained from the airport facility; and

O_{ik} = total operations for n months of year k, based on data obtained from the airport facility.

The adjusted data for the inventory year is:

$$\sum O_j = f \times \sum O_k \qquad (5\text{-}2)$$

where O_j = total adjusted number of aircraft operations for inventory year j,

O_k = total aircraft operations reported in References 2 and 3 for year k, and

f = adjustment factor derived in Equation (5-1).

Separate adjustment factors can be derived from commercial and general aviation activity.

The number of operations occuring at military airfields may be more difficult to obtain. The Air Force releases a summary of the number of opertions occurring at its facilities under the title of Air Traffic Control Operations,[4] but specific data regarding the types of aircraft involved are not routinely available. In specific instances, the operations officer at the installation should be contacted to determine what data can be made available. As a minimum, the total number of military aircraft operations for a particular year should be determinable. In addition, military installations are required to report air pollution data to the U.S. Environmental Protection Agency. State and local agencies should contact their regional EPA office for these data.

5.2.2 CALCULATION OF EMISSIONS

The basis for calculating emissions from the aircraft operations determined in the previous step is a set of emission factors provided for civil and military aircraft, respectively, in Tables 3.2.1-9 and 3.2.1-10 of AP-42.[1] These emission factors are presented in terms of total quantity of pollutant produced during each LTO cycle, by type of aircraft. For commercial aircraft, the activity data derived from Reference 3 are in terms of aircraft departures, the number of which is equal to the number of LTO cycles. On the other hand, the aircraft activity data contained in Reference 2, for general other hand, the aircraft activity data contained in Reference 2, for general aviation (as well as for the other categories), is for specified aircraft operations, which are either a landing or a takeoff; therefore, the total operations must be divided by 2 to obtain the number of LTO cycles. Emissions are calculated by:

$$E_{ij} = (LTO)_j \times (ELTO)_{ij} \tag{5-3}$$

where E_{ij} = total emissions of pollutant i, in pounds or kilograms, produced by aircraft type j;

$(LTO)_j$ = number of LTO cycles by aircraft type j; and

$(ELTO)_{ij}$ = emission rate, in pounds or kilograms of pollutant i per LTO cycle, for aircraft type j.

The emission factor for each type of commercial aircraft is obtained from Table 3.2.1-9 in AP-42.[1] It may not be possible to identify specific types of aircraft in either the general aviation category or the military category. Where this occurs, a general emission factor, in grams of pollutant produced during each LTO cycle can be applied; these general factors were developed by the EPA and are presented here in Table 5-3.

5.3 METHOD 2--ANALYSIS OF TIME-IN-MODE TO ESTIMATE EMISSIONS

This method is used where more detailed air quality modeling is contemplated, therefore justifying a more comprehensive analysis of emissions produced by aircraft activity. The focus of this method is the actual time spent in each of the five modes (i.e., approach, taxi/idle in, taxi/idle out, takeoff, and climbout) by each type of aircraft. Whereas Method 1 utilizes a generalized set of assumptions regarding the time spent in each mode during

TABLE 5-3. COMPOSITE LTO CYCLE EMISSION FACTORS FOR THREE GENERAL AIRCRAFT CATEGORIES

	Emission factor (lbs per LTO cycle)				
Category	Particulates	SO_x	NO_x	HC	CO
Commercial	1.18	2.84	26.93	30.66	67.46
General avaiation	0.02	0.01	0.028	0.41	18.8
Military	15.23	1.43	9.16	27.1	48.8

Source: Charles O. Mann. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Telephone conversation on 10 March 1981.

the LTO cycle, this method allows the analyst to specify the duration of each mode to reflect actual conditions prevailing at the airport and to calculate emissions accordingly. In an overall sense, the two methods are similar in that the basis for estimating emissions is the time-in-mode associated with the LTO cycle.

5.3.1 DERIVATION OF AN ACTIVITY FACTOR

In this method emphasis is placed on deriving an activity factor that is sensitive to local conditions affecting emissions attributable to aircraft operations. Certain meteorological conditions affect the amount of pollution contributed by aircraft operations, since only a portion of the total emissions produced by these sources has an effect on ground level concentrations. Specifically, only emissions produced while the aircraft is operated within the limits of the above ground inversion are of interest. The layer between the ground and the top of the inversion is referred to as the mixing layer and is described in terms of its depth or height. Mixing height varies, for example, as a function of geographical location, topography, wind conditions, cloud cover, season of the year, and time of day. Variations in mixing height are illustrated in Figures 5-3, 5-4, and 5-5, which, respectively show mean summer morning, mean summer afternoon, and mean winter afternoon mixing heights. The variations in this parameter as a function of both time of day and season are readily apparent. The implication is that the portion of emissions produced while the aircraft is aloft that should be ascribed to the area being inventoried is also a function of diurnal and temporal variations in the local mixing height. For emission inventorying purposes, the specific modes during the LTO cycle that are affected by variations in the mixing height are the approach mode and the climbout modes. Implicit in the Method 1 technique is the assumption that the mixing depth is 3000 feet (914 meters).[1]

Specific time-in-mode (TIM) for all modes in the LTO cycle are implicitly assumed in Method 1. The TIM for approach and climbout are based on the performance characteristics of each type of aircraft and the 3000 foot mixing height. Taxi/idle in and taxi/idle out TIMs are based on empirical data from a large metropolitan airport during the busiest period of the day.[4,5] The resulting TIMs for these two modes used in Method 1 tend to be longer than those likely to occur during most periods of the day at any airport. The TIM for the takeoff mode is a function of the performance characteristics of the aircraft, and therefore is not likely to be affected by local conditions. Specific TIMs assumed in Method 1 are presented here in Table 5-4.

The first step in deriving activity factors for Method 2 is to identify all airports and determine the number of types of aircraft using each airport during the period to be represented by the inventory. The same basic data sources are used for both Methods 1 and 2. However, it is more desirable to identify the specific types of all aircraft, including general aviation and military aircraft, for Method 2. If specific data concerning general aviation aircraft operations cannot be obtained from the airport operations officials, then census data developed by the Federal Aviation Administration (FAA) and

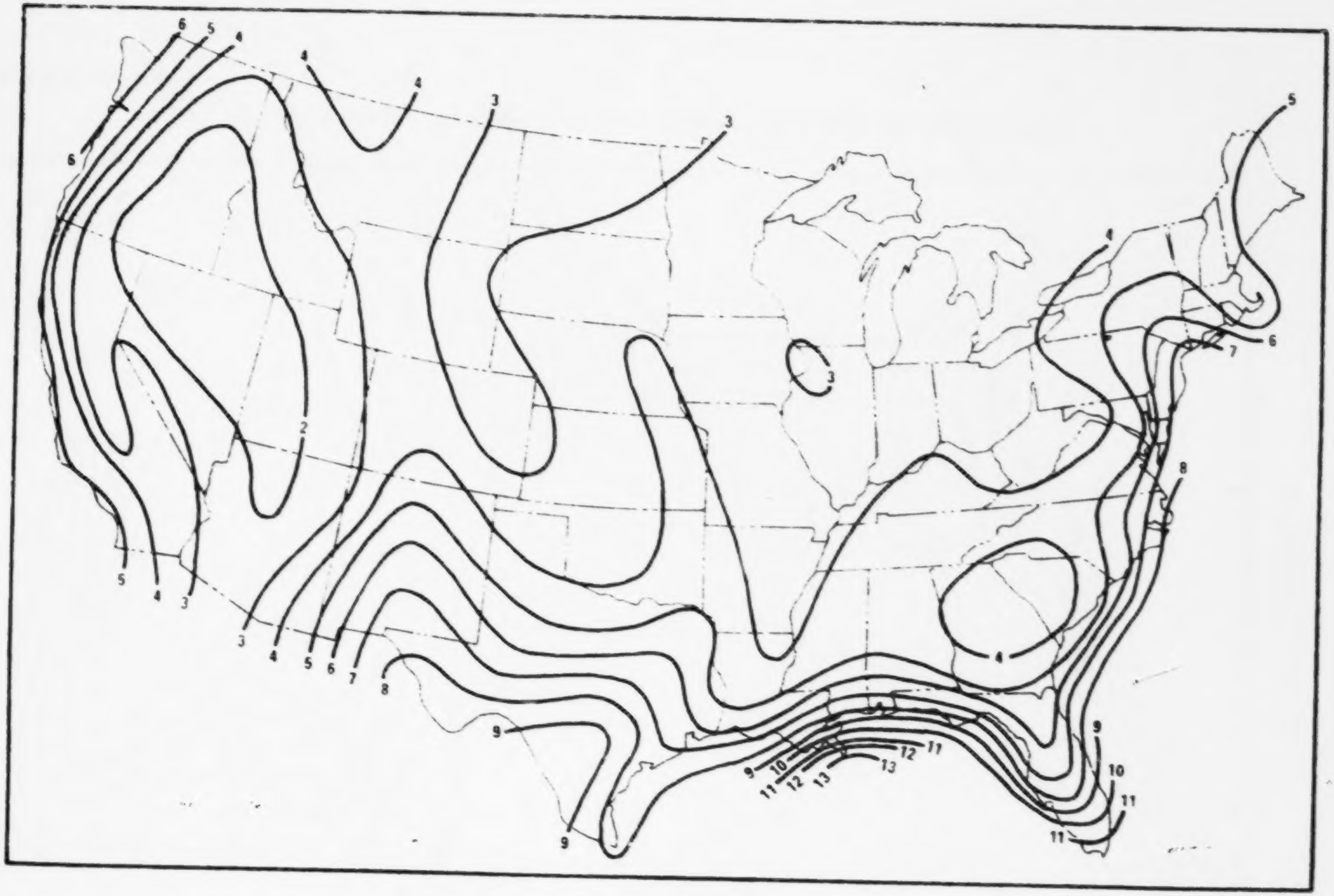
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Figure 5-3. Isopleths (m x 10^2) of mean summer morning mixing heights.

Source: Reference 7.

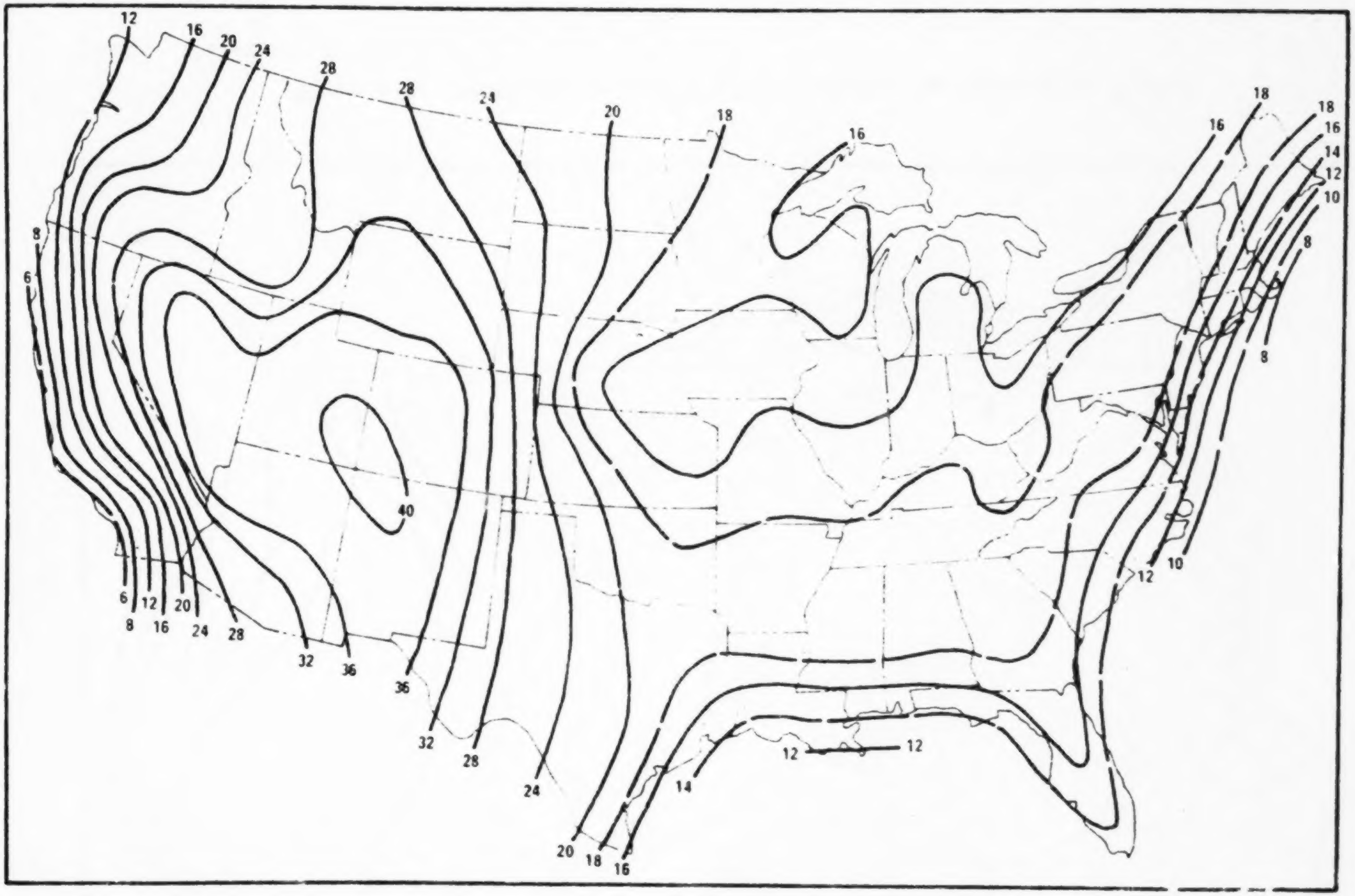
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Figure 5-4. Isopleths (m x 10^2) of mean summer afternoon mixing heights.

Source: Reference 7.

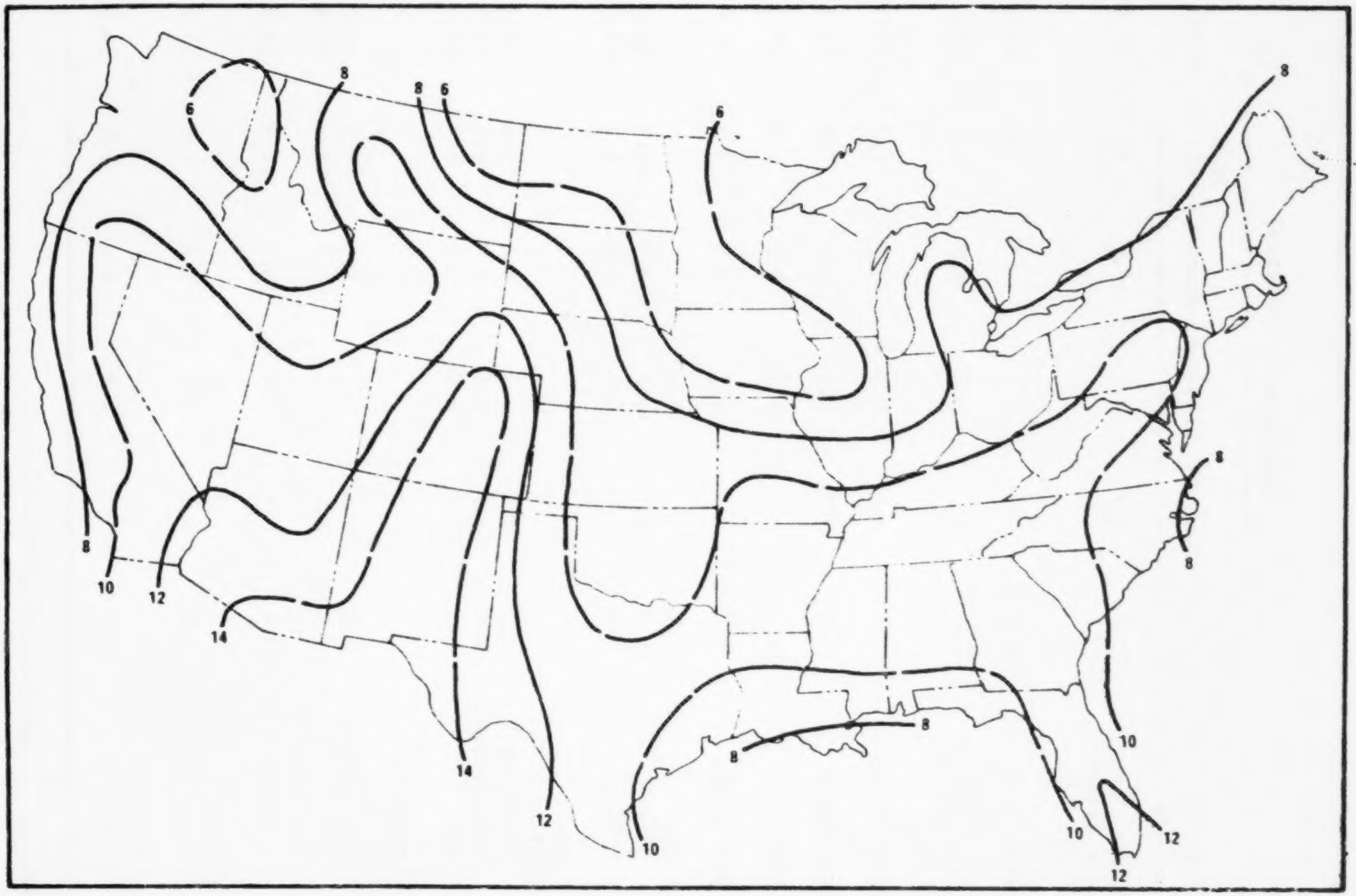
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Figure 5-5. Isopleths (m x 10^2) of mean winter afternoon mixing heights.

Source: Reference 7.

TABLE 5-4. TIME-IN-MODE DATA USED TO DEVELOP GENERALIZED EMISSION FACTORS FOR LTO CYCLES

Aircraft category	Aircraft type	Time-in-mode (minutes)					
		Taxi/ idle out	Takeoff	Climbout	Approach	Taxi/ idle in	Total
Commercial carrier[a]	Jumbo, long and medium range jet	19.0	0.7	2.2	4.0	7.0	32.9
	Turboprop	19.0	0.5	2.5	4.5	7.0	33.5
	Transport--piston	6.5	0.6	5.0	4.6	6.5	23.2
General aviation[a]	Business jet	6.5	0.4	0.5	1.6	6.5	15.5
	Turboprop	19.0	0.5	2.5	4.5	7.0	33.5
	Piston	12.0	0.3	5.0	6.0	4.0	27.3
	Helicopter	3.5	-	6.5	6.5	3.5	20.0
Military[b]	Combat						
	USAF	18.5	0.4	0.8	3.5	11.3	34.5
	USN	6.5	0.4	0.5	1.6	6.5	15.5
	Trainer--Turbine						
	USAF T-38	12.8	0.4	0.9	3.8	6.4	24.3
	USAF general	6.8	0.5	1.4	4.0	4.4	17.1
	USN	6.5	0.4	0.5	1.6	6.5	15.5
	Transport--Turbine						
	USAF general	9.2	0.4	1.2	5.1	6.7	22.6
	USN	19.0	0.5	2.5	4.5	7.0	33.5
	USAF B-52 and KC-135	32.8	0.7	1.6	5.2	14.9	55.2
	Military--Piston	6.5	0.6	5.0	4.6	6.5	23.2
	Military--Helicopter	8.0	-	6.8	6.8	7.0	28.6

Source: Reference 1, Tables 3.2.1-3 and 3.2.1-4.

[a] Reference 4.

[b] Reference 5.

reported in Census of U.S. Civil Aircraft[6] can be used to identify the types of aircraft registered with FAA in the county or counties being inventoried. Appendix B of Reference 6 lists the number of general aviation aircraft registered in each county in the U.S. by engine type (i.e., piston, turboprop, and turbojet), number of engines, and seating capacity for both fixed wing and rotory wing aircraft. The data regarding the type distribution of aircraft registered in the county is used as the basis for a type distribution for all general aviation aircraft using the airports in the inventory area.

As part of the data collection effort regarding the types of aircraft using the region's airports, information must be obtained on certain characteristics of each type of aircraft. Specifically, the number and type of engine used (i.e., piston, turboprop, or turbojet), its manufacturer, and the model designation must be identified. This information is required since the aircraft emission factors that will be applied are specified by engine type, model, and manufacturer, and are presented in terms of emissions per hour of operation in each mode, per engine. This information can be obtained from Tables 3.2.1-1 and 3.2.1-2 of Reference 1 (see Tables 5-1 and 5-2, here) and from References 3 and 6.

The next step is to derive specific TIM data for each type of aircraft. This is done separately for the approach and climbout modes, the taxi/idle out and taxi/idle in modes, and the takeoff mode. The TIMs for the approach and climbout modes can be estimated for each aircraft type using local meteorological data representing the inventory period. Specifically, mixing height data is usually maintained on an ongoing basis by the weather station at each airport. The inversion height is measured and recorded several times each day; therefore mixing height data for several periods during any particular day should be available. The mixing height used should reflect a weighted average for a day during the season for which emissions are being inventoried. The weighted height is:

$$\overline{H} = \sum_{i=1}^{n} (N_i \times H_i) \Big/ \sum_{i=1}^{n} N_i \qquad (5\text{-}4)$$

where $\overline{H}$ = weighted average mixing height, in feet or meters, during the day of interest;

N_i = number of LTO cycles occurring period i on the day of interest; and

H_i = mixing height, in feet/meters, during period i on the day of interest.

To calculate $\overline{H}$, data must be available concerning the diurnal distribution of LTO cycles. This information can be obtained from the airport operations office. Mixing height data are obtained from the airport weather station.

To calculate TIMs for the approach and climbout modes for each type of aircraft, data contained in Table 5-4 (from Reference 1, Tables 3.2.1-3 and 3.2.1-4) are adjusted as a function of the relative difference between the local weighted average mixing height, and the assumed mixing height on which the TIMs in Table 5-4 were based. Specifically, TIMs are calculated as:

$$TIM'_{app} = (\overline{H} / H_{as}) \times TIM_{app} \qquad (5\text{-}5)$$

$$TIM'_{clm} = [(\overline{H}-500) / (H_{as}-500)] \times TIM_{clm} \qquad (5\text{-}6)$$

where TIM'_{app} = adjusted approach time-in-mode, in minutes, reflecting local mixing height;

$\overline{H}$ = weighted average mixing height, in feet or meters, for the local area during the day of interest;

H_{as} = assumed mixing height, in feet or meters, from which TIMs were computed in Reference 1, which has a value of 3000 feet;

TIM_{app} = time-in-mode, in minutes, for the approach mode from Table 5-4;

TIM'_{clm} = adjusted climbout time-in-mode, in minutes, reflecting local mixing height; and

TIM_{clm} = time-in-mode, in minutes, for the climbout mode from Table 5-4.

In Equation (5-6) the $\overline{H}$ and H_{as} values are both decreased by 500 feet to account for the fact that the climbout mode begins after the aircraft is actually airborne and the throttle power setting is cut back from 100 percent to 75 percent. This point where the power setting is cut back, ends the takeoff mode and initiates the climbout mode. It is assumed here that a representative altitude where this change of mode occurs is 500 feet.

The next step is to define the TIMs associated with taxi/idle in and taxi/idle out modes. The only method that can be used to derive local values for these TIMs is to observe actual aircraft operations at the facility being considered. If field studies cannot be made, then the alternative is to use the values shown in Table 5-4. It is not likely that in the context of emission inventory development, significant improvements could be made in the accuracy of the TIM data for the taxi/idle mode presented in Table 5-4. These values should be used unless some readily available data indicate otherwise.

In most instances, data concerning the specific types of military aircraft operating at military bases will not be available. A general indication of the distribution of aircraft by category (i.e., jet transports, piston engine transports, trainers, high performance aircraft, etc.) may be determinable. These general categories should be used where more specific data cannot be provided. The source for military data is the airfield operations officer and the regional U.S. Environmental Protection Agency office.

5.3.2 CALCULATION OF EMISSIONS

The emissions produced by each type of aircraft during each mode of the LTO cycle are calculated as a function of the TIM, the number of engines used by the particular type of aircraft, and the mode-specific emission factor for each type of aircraft (actually, for each type of aircraft engine). The following equation illustrates the calculation:

$$E_{ij} = \sum_{k=1}^{5} (TIM_{jk}/60) \times (EF_{ijk}) \times (NE_j) \qquad (5\text{-}7)$$

where E_{ij} = total emissions, in pounds, of pollutant i produced by aircraft type j;

TIM_{jk} = time-in-mode, in minutes, for mode k for aircraft type j;

EF_{ijk} = emission factor, in pounds of pollutant i per hour of operations in mode k, for each engine used on type j aircraft; and

NE_j = number of engines used on type j aircraft.

Total emissions produced by the entire source category is:

$$E_{Ti} = \sum_{j=1}^{n} E_{ij} \qquad (5\text{-}8)$$

where E_{Ti} = total emissions, in pounds, of pollutant i produced by types j through n aircraft operating in the inventory area; and

E_{ij} = defined in Equation (5-7).

5.4 INVENTORY MAINTENANCE

Two factors are of concern in terms of inventory maintenance. First, changes in the level of activity at a particular facility will result in an increase or reduction of emissions. General trends in airport activity can be monitored using the data provided in References 2 and 3, which are annual publications. The second factor concerns changes in the types of aircraft using the facility. The current trend in the airlines industry (in fact, in all segments of the transportation industry) is to replace older equipment with modern, fuel efficient types. This turnover in the types of aircraft being used, will also be reflected in the emissions produced. Periodic reviews must be made of the literature to remain current in terms of the types of changes occurring in the types of aircraft being used, and also in terms of the relative differences in the emission characteristics of the older and newer aircraft. The intent should be to remain cognizant of revisions in either recommended emission inventorying techniques, or in basic emission factors for each emission source.

Every airport will have non-aircraft originated emissions as a result of operation (off-highway fuel use, plane and vehicle fueling, fuel storage, fugitive dust). It is imperative that these emissions be accounted for in the emission inventory. Procedures for estimating these emissions are presented in Volumes II and III of this series.[8,9]

References for Chapter 5.0

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4. Control of Air Pollution for Aircraft and Aircraft Engines, 38 FR 19088, July 17, 1973.

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6.0 EMISSIONS FROM RAILROADS

The primary interest when inventorying railroads is emissions from locomotives. Railroad locomotives used in the U.S. are primarily of two types--electric and diesel-electric. Electric locomotives are powered by electricity generated at stationary power plants and distributed by either a third rail or overhead catenary system. Emissions are produced only at the electrical generation plant, which is considered a point source and therefore not of interest here. A diesel-electric locomotive, on the other hand, uses a diesel engine and generator to produce the electricity required to power its electric traction motors. Emissions produced by large diesel engines are of interest in emission inventory development. Methods are presented here for inventorying emissions from diesel-electric locomotives.

Other locomotives may be in use, including steam locomotives, diesel-hydraulic, and gas-turbine locomotives. Their numbers and emissions are insignificant compared to diesel-electric locomotives. Steam locomotives are used in very localized operations, primarily as tourist attractions. These locomotives are insignificant in terms of the quantity of emissions that they produce. Diesel-hydraulic locomotives are generally high-horsepower units used in areas where trains must be hauled over steep grades. Given the similarity between these locomotives and diesel-electric locomotives, emission estimates can be developed using the same methods. Gas turbine locomotives have been used to some extent since the early 1950's for various line-haul operations. Their numbers are insignificant relative to diesel-electric and electric locomotives.

6.1 OVERVIEW OF INVENTORY METHODS

Presented here are two basic methods for inventorying emissions from diesel-electric locomotives. Both methods require the derivation of an activity factor, and an appropriate emission factor defined as a function of the activity factor. The first approach uses the quantity of fuel consumed for railroad operations, which represents the activity factor, and an emission factor from AP-42[1] defined in terms of emissions produced per gallon of fuel burned. The second approach is somewhat more detailed, involving the derivation of work output estimates for locomotives and the application of an emission factor from AP-42. Each method is presented separately in following sections.

6.2 METHOD 1--EMISSION ESTIMATES BASED ON FUEL USE

This approach to inventorying emissions from railroad locomotives involves the derivation of an activity factor based on the quantity of fuel used by locomotives. The estimated fuel use is then used with an emission factor, defined in terms of quantity of pollutant produced per gallon of fuel burned, to derive the emission estimates.

6.2.1 DERIVATION OF THE ACTIVITY FACTOR

The activity factor for locomotives operating in the study area can be derived using any of several methods. All are based on allocating a share of the total fuel used state-wide by locomotives to smaller areas of the state.

Annual fuel use by railroad locomotives is reported for each state in a U.S. Department of Energy publication entitled Energy Data Reports.[2] This report is published during the last quarter of the year subsequent to the reporting year (i.e., data for 1978 were published in November 1979).

The allocation of state-wide fuel use to a study area is based on identifying an appropriate surrogate parameter whose relative distribution (study area to state-wide) can be assumed to approximate the relative level of railroad activity. Surrogates are railroad track mileage, freight density, and population. The use of each of these to apportion state-wide fuel use data is discussed separately.

6.2.1.1 Apportioning State Fuel Use Data Based on Track Mileage

This method of apportioning state fuel use to a particular region assumes that usage is directly proportional to miles of track.* Study area fuel use by locomotives is estimated as:

$$Q_i = Q_T \times (M_i/M_T) \qquad (6\text{-}1)$$

where Q_i = the estimated quantity of fuel consumed in study area i, in gallons/year;

Q_T = the quantity of fuel used in the state by railroads, obtained from Reference 2, in gallons/year;

M_i = the miles of active railroad track located in study area i; and

M_T = total miles of active railroad track located in the state.

Total and study area track mileage can be obtained by state from several sources. The first source to consider is the State Transportation agency. Since the mid 1970's, states have been required to develop and maintain a comprehensive rail transportation plan in order to be eligible for funding under the Federal Railroad Administration's Federal Rail Service Assistance Program.[3] These plans contain data concerning rail service within the state and also define various characteristics of the rail network, including mileage. The rail plan document and the state agency responsible for its publication are, therefore, valuable sources of data.

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*Excluding track used exclusively by electric locomotives.

Another source of information for state track mileage is a document published periodically by the Association of American Railroads, entitled Railroad Mileage by States.[4] This document tabulates, for each state the number of miles of right-of-way operated by each railroad company, and the track-miles operated by terminal and switching companies. The most current edition was published in December 1978 reflecting mileage as of December 1977.*

There is no single data source that can be specified here for obtaining track-miles for sub-areas of states (i.e., emission inventory study areas). Tabulations of track-mile data may be available for counties, SMSAs, or urban areas from some state transportation agencies, or from the county or metropolitan planning organization within whose jurisdiction the study area is located. Alternatively, track-miles can be obtained by direct measurement from an appropriate map, such as the County Series maps (obtained from the state transportation agency), U.S. Geologic Survey maps, U.S. Transportation Zone Maps, or locally prepared maps. If direct measurements are used, the mileage parameter should be the same as that reflected by the state-level data; that is, if the state-level data are in terms of total right-of-way miles, the measured parameter for the study area should also be right-of-way miles.**

In urban areas, measuring railroad (track or right-of-way) mileage can become somewhat confusing, particularly around switch yard and terminal areas. It is desirable to account for the higher level of activity in terminal areas and switchyards, yet measuring the actual track mileage in these areas may be very difficult and the use of the total track miles in these areas may overstate their significance. Instead, it is recommended that, in areas with railroad terminals, siding tracks be ignored. A siding track is a dead end track that has no further branches along its length. These are apparent when examining a map.

For switchyards, an expedient method is used which accounts for switchyard activity as a function of urban area population, rather than track mileage. The distance through the switchyard is measured and multiplied by a factor that varies according to the population of the area where the switchyard is located. These factors are shown in Table 6-1.

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*At the time of publication of this document, the 1978 edition of Railroad Mileage by States was the most recent edition.

**It is noted that in the literature, mileage statistics are often specified in terms of route-miles, which is synonymous to right-of-way miles.

TABLE 6-1. SWITCHYARD MILEAGE FACTORS (f)

Urban area population	Switchyard factor
Less than 50,000	5
50,000-100,000	10
100,000-250,000	15
Over 250,000	20

In Equation (6-1), the value of M_i, track-mileage within study area i, is determined from:

$$M_i = M_{ML_i} + M_{Si} + (f_i \times M_{SYi}) \tag{6-2}$$

where M_i = track mileage within study area i;

M_{MLi} = miles of mainline and branchline track (or right-of-way) in area i;

M_{Si} = miles of spur track in area i;

M_{SYi} = total distance, in miles, through all switchyards located in area i; and

f_i = the switchyard mileage factor from Table 6-1.

6.2.1.2 Apportioning State Fuel Use Data Based on Freight Density

An alternative method for apportioning statewide fuel consumption involves the use of freight density statistics for the primary rail line branches in the state. Freight density is the gross ton-miles carried per track mile. In this statistic, gross ton-miles accounts for the total weight of both freight and railroad cars moved over the track. Freight density statistics are obtained from several sources, including State Rail Plans, state agencies responsible for rail planning or regulation, and direct interviews with railroad officials.

An equivalent density factor must be derived for intercity and commuter rail activity. This factor is developed for passenger train traffic for each line as a function of frequency of service (trains per year), the typical makeup of the train (that is, the number of cars), and the route mileage of the line. This information can be obtained from direct interviews with railroad officials. The density is:

$$D_{ji} = W \times N_{cji} \times N_{TJi} \times 10^{-6} \tag{6-3}$$

where D_{ji} = the annual passenger train density in million gross ton-miles per track mile on line j, in area i;

W = average gross weight of a passenger car, in tons (in the absence of specific data, a value of 60 tons can be used);

N_{cji} = typical number of cars in trains using line j, in area i; and

N_{Tji} = frequency of service on line j, in area i; in trains per year.

Passenger line mileage and density must be calculated for the entire state by substituting values reflecting state-wide values for N_c and N_T into Equation (6-3).

The estimated fuel use in the inventory area is derived by:

$$Q_i = \left[Q_T\right] \times \frac{\sum_j^m \left(L_j D_j\right)_i + \sum_j^m \left(L_j' D_j'\right)_i}{\sum_j^n \left(L_j D_j\right)_s + \sum_j^n \left(L_j' D_j'\right)_s} \tag{6-4}$$

where Q_i and Q_T are as defined in Equation (6-1),

$\sum_j^m (L_j D_j)_i$ = the summation of the product of individual rail line length L (in miles) and density D (in millions of gross ton-miles per mile), for freight lines j through m within study area i;

$\sum_j^n (L_j D_j)_s$ = the summation of the product of individual rail line length L (in miles), and density D (in millions of gross ton-miles per mile), for freight lines j through n within state s;

$\sum_j^m (L_j' D_j')_i$ = the summation of the product of individual rail line length L (in miles) and density D (in millions of gross ton-miles per mile), for passenger lines j through m within study area i; and

$\sum_j^n (L_j' D_j')_s$ = the summation of the product of individual rail line length L (in miles) and density D (in millions of gross ton-miles per mile), for passenger lines j through n within state s.

6.2.1.3 Apportioning State Fuel Use Data Based on Population

This is the easiest method to apply since it relies on population data, which are usually available. The study area fuel use is estimated from:

$$Q_i = Q_T \times (P_i/P_T) \qquad (6\text{-}5)$$

where Q_i and Q_T are as defined in Equation (6-1),

P_i = area i population, and

P_T = total statewide population.

6.2.2 DERIVATION OF EMISSION ESTIMATES

To derive an estimate of the emissions produced in the study area as a result of railroad activity, an emission factor is applied to the fuel use estimated, Q_i. The emission factors used are obtained from AP-42, Table 3.2.2-1.[1]

The estimated annual emissions of each pollutant is:

$$E_{pi} = Q_i \times EF_p \qquad (6\text{-}6)$$

where E_{pi} = mass of emissions (in tons or kg per year) of pollutant p, produced by railroad locomotives in area i;

Q_i = annual quantity of fuel used by locomotives in study area i; and

EF_p = emission factor for pollutant p, from Table 3.2.2-1 in Reference 1.

6.3 METHOD 2--EMISSION ESTIMATES BASED ON WORK OUTPUT

A more accurate estimation of emissions produced by railroad locomotives, than Method 1 provides, can be effected through a more detailed examination of the usage of rail lines. The intent is to derive an activity factor based on the estimated total annual or daily horsepower-hours (work output) expended by different types of locomotives. The activity factor is then used with an emission factor to develop the emission estimate.

6.3.1 DERIVATION OF THE ACTIVITY FACTOR

Activity factors in terms of horsepower-hours per day or year by locomotive type are derived for each rail line, as well as for all switchyards and terminals. The data required to develop the activity factors must be obtained by direct interviews with railroad offícals involved in operations. Interviews (as opposed to sending questionnaires) are required if this method is to yield more precise results than those of Method 1.

6.3.1.1 Data Requirements and Collection

Rail operations can be categorized as line-haul, transfer, or switch activity. Line-haul operations concern the movement of trains between urban areas, with only limited switching activity to add or delete cars from the train. Transfer activity is the movement of trains among yards generally within the same urban area. Here, both line-haul and switching operations occur but the size of the trains is much smaller than for the line-haul category, and the switching activity occurs primarily in terminal areas. The last category, switching, refers to the movement of train cars within rail classification yards and to terminals located in or near these switchyards. Owing to the significant differences in both the types of locomotive used and the conditions under which they are operated (hence, in emission characteristics), it is necessary to develop separate activity factors for each type of operation.

The first step in the derivation of activity factors is to obtain maps of the study area that depict the rail lines and indicate the operator of each. County Series maps, U.S. Geologic Survey maps, U.S. Department of Transportation Zone Maps, or locally prepared maps can be used.

The next step is to contact each railroad to arrange an interview with an appropriate official--usually one involved with operations. The purpose of the interview is to obtain data for each rail line concerning:

the number of trains per day (per week or per year) using each line;

the estimated average number of locomotive units per train for each line;

the average operating speed over the line; and

the length of the line.

This information must be defined separately for line-haul and transfer operations. For switching operations, an estimate of the daily, weekly, or annual locomotive-hours of operation is required.

Also during the interview, information should be obtained concerning the type of locomotives routinely used on each line for each type of operation. The specific locomotive categories that are of interest are defined in terms of engine type and horsepower class. The requirement is to determine the distribution of each locomotive type, for each type of operation, on each rail line. Specific locomotive categories include:

2-cycle supercharged, by horsepower rating;

2-cycle turbocharged, by horsepower rating; and

4-cycle, by horsepower rating.

Horsepower rating can be aggregated by range, using:

600-899 horsepower (hp),

900-1199 hp,

1200-1599 hp,

1600-1999 hp,

2000-2399 hp,

2400-2999 hp,

3000-3599 hp,

3600-4199 hp, and

4200 hp and over.

For each rail line, as well as for each switchyard and terminal, a data file should be developed similar to that shown in Figure 6-1.

The data should represent each rail line, or various segments of each rail line if operations are different on each segment. Also, information concerning temporal and diurnal rail traffic patterns and other points that could have a bearing on emissions in the future (e.g., expansion or contraction of service, new service, new equipment, etc.) should be identified.

6.3.1.2 Calculation of the Activity Factor

The two sets of data (rail line specific and locomotive specific) obtained for each line are analyzed to derive an estimate of the daily or annual locomotive-hours or use, by each type of locomotive (engine type and horsepower class), for each type of operation (line-haul, and transfer)*, using:

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*Locomotive-hours for switching operations should be obtained directly from the interviews.

Interview By: Date:

Person Interviewed: Title:

Affiliation: Phone No.

Address:

Rail Line:

General Location: From: To:

Line or segment length: miles.

Calendar Year Represented:

Line-Haul Operations:

Number of trains per day, week, or hear (state which)

Average number of locomotives per train:

Average train speed: mph

Percentage of locomotives by type:

Record percentage of all line-haul locomotives using the line by locomotive type:

Percentage of Locomotives by Type

	Maximum Horsepower Rating							
Engine Type	600-900	900-1200	1200-1600	1600-2000	2000-2400	2400-3000	3000-3600	3600-4200	Other (specify)
2-Cycle, Supercharged									
2-Cycle, Turbocharged									
4-Cycle									

Figure 6-1. Interview record/data file for railroads.

Transfer Operations:

(Record same data as for line-haul)

Switching Operations:

Record the average daily, weekly, or annual (specify which) locomotive-hours expended in switching operations for each locomotive type:

-Hours of Operation by Locomotive Type

	Maximum Horsepower Rating							
Engine Type	600-900	900-1200	1200-1600	1600-2000	2000-2400	2400-3000	3000-3600	3600-4200	Other (specify)
2-Cycle, Supercharged									
2-Cycle, Turbocharged									
4-Cycle									

Remarks: Indicate seasonal usage patterns, projected levels of service, etc., that might have an impact on emissions.

Figure 6-1 (continued).

$$h_k = (L/S) \times (P_k) \times (N) \qquad (6\text{-}6)$$

where h_k = daily or annual hours of operation of locomotive type k, within the study area;

L = length, in miles (kilometers), of the line being analyzed within the study area;

S = average train speed in miles (kilometers) per hour, over the line;

P_k = percent of total equipment-hours for the line represented by locomotive type k; and

N = number of trains per day (or year) times the number of type k locomotives per train.

The next step is to calculate the work output in horsepower-hours for each type of locomotive for each of the three types of operation. This is done using:

$$w_k = l \times P_k \times h_k \qquad (6\text{-}7)$$

where w_k = work output for locomotive type k, in horsepower-hours;

l = load factor, which accounts for variations in output during the operation of a locomotive;

P_k = available horsepower, taken as the average for the horsepower range class (see Figure 6-1) for locomotive type k; and

h_k = daily hours of operation per day (or year) by locomotive type k, from Equation (6-6).

The load factor, l, in Equation (6-7) has a value of 0.4 for line-haul, 0.2 for transfer, and 0.06 for switching-operations.[1] The result will be a work output estimate for each type of locomotive used in each of three types of operation, for each rail line or segment thereof.

6.3.2 CALCULATION OF EMISSIONS

Emissions are computed for each rail line based on the estimated work output by each locomotive category, from Equation (6-7), and an emission factor defined in terms of grams of pollutant per horsepower-hour for each type of locomotive. The emission factors are found in Table 3.2.2-2 of AP-42.[1] Table 3.2.2-2 in AP-42 contains emission factors for the following locomotive categories:

2-cycle, supercharged switch engines;

2-cycle, supercharged road engines;

2-cycle, turbocharged road engines;

4-cycle, switch engines; and

4-cycle, road engines.

To use these emission factors, assume that the breakpoint between road engines and switch engines in Table 3.2.2-2 of AP-42 is 1800 horsepower; therefore the emission factors for switch engines will be used for calculating emissions for locomotives less than 1800 horsepower, while the road engine emission factors would be used for locomotives rated at 1800 horsepower or more.

6.4 TEMPORAL DISTRIBUTION

Seasonal variations in railroad activity occur. Temporal variations in activity are determined through direct interviews with officials associated with the railroads operating within the study area.

It is also necessary, in some applications, to develop an estimate of daily emissions during a specific season (e.g., during the summer if the inventory is to support ozone modeling efforts). Where seasonal variations are judged insignificant, daily emissions can be estimated by dividing the total annual emissions produced by 300 days per year. Similarly, if a particulate month reflects exceptionally high activity, the daily emissions can be estimated by dividing the total estimated emissions for that month by 24 days per month.

Although most railroads operate 24 hours a day all year, the day-per-year and day-per-month figures suggested here are intended to weight emissions toward a weekday when most activity, and hence emissions, occur. If more precise data are available from local sources, they should be used.

6.5 EMISSION FORECASTS

The railroad industry is experiencing both growth and contraction, depending largely on the geographic location considered. The most reliable indications regarding future levels of activity are obtained by direct interviews with officials representing the railroads in the study area. Alternatively, a general scenario for future railroad activity has been proposed by the Association of American Railroads,[9] which provides a basis for projecting future emissions for inventorying purposes.

References for Chapter 6.0

1. Compilation of Air Pollution Emission Factors, Third Edition and Supplements, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1980.

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3. Part 266, 49 CFR, U.S. Department of Transportation.

4. Railroad Mileage by States, Association of American Railroads, December 31, 1977.

5. Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines. Part 1. Locomotive Diesel Engines and Marine Counterparts, APTD-1490, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1972.

6. Young, T. C., Unpublished Data from the Engine Manufacturers Association, Chicago, IL, May 1970.

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8. Wiltsee, Kenneth W., Jr., A Methodology and Inventory for Fuel Use and Emissions from Railroads in the St. Louis Air Quality Control Region for the Regional Air Pollution Study, Walden Division of Abcor, Inc., April 1977.

9. Yearbook of Railroad Facts, Association of American Railroads, Washington, DC, Published annually.

7.0 EMISSIONS FROM VESSELS

In some areas a significant amount of recreational and commercial marine activity occurs, which contributes to the region's total emission output. In spite of the relatively small emission contribution generally attributed to marine activity, an accounting must be made of these sources if the overall emission inventory is to be considered complete. The purpose of this chapter is to define methods used to inventory and estimate emissions produced by marine activity.

For purposes of developing emission inventories, marine activity can be classified as either recreational or commercial (including military). These two categories reflect differences in both vessel size and usage characteristics, and reflect basic differences in the methods applied to estimate emissions. Recreational boating includes vessels generally less than 100 feet in length, most being less than 30 feet. These vessels are powered either by outboard or inboard engines. Outboard engines range in size from 1 horsepower to over 200 horsepower, are gasoline powered (Otto cycle), and are usually designed to operate on a 2-stroke cycle. Inboard engines range in size upwards from less than 10 horsepower for auxiliary engines or from approximately 60 horsepower for main engines, and may be either gasoline or diesel. Most of these engines tend to resemble automobile engines in terms of basic design, size, and performance. A third category--inboard/outboard--utilize an inboard engine with an outboard drive assembly. These can be considered with the inboard category for purposes of emission inventory development.

There tends to be very little control or regulation regarding the use of recreational vessels. States usually require that boats be registered and some regulation exists on safety, but there usually are no agencies at any level of government that maintain data regarding the actual usage--location and hours of operation--of recreational vessels.

Commercial vessels include all boats and ships used either directly or indirectly in the conduct of commerce or military activity. These include vessels ranging in size from 20-foot charter boats to the largest tankers and military vessels, which can exceed 1000 feet in length. In spite of the large range of vessels represented by this category, several points of commonality exist that are particularly relevant in terms of emission production. First, the majority of vessels in this category are powered either by diesel engines or steam turbines. Diesel engines are used throughout the range of vessels in this category, are the engine most often used in large foreign vessels, and are becoming more popular in the U.S. as well.[1]

Advances in the design of very large, low-speed, 2-cycle diesel engines have resulted in the production and use of engines ranging up to 36,000 shaft-horsepower (SHP). Although heavier and requiring more maintenance than steam turbine propulsion systems, the low speed diesel engine is capable of significantly more efficient fuel use. Current large diesels may have a specific fuel consumption rate as low as 0.35 lb per SHP-hour, compared with a typical rate of 0.56 lb per SHP-hour for steam boiler/turbine systems using essentially the same type fuel.[1] In addition to steam turbine and diesel propulsion, gas turbine powered vessels may be found. These are used primarily on certain military vessels designed for high speed operation, or on high performance civilian vessels such as hydrofoils or surface-effect vehicles. On larger military vessels, these systems are often used only when the vessel is out to sea, while during maneuvering operations in port areas auxiliary diesel engines are used. The gas turbine engines used on high performance vessels are very similar to aircraft engines. Most commercial and larger military ships produce their own power while at dockside for operating winches, pumps, ventilation fans, refrigeration, lights and electrical equipment, etc. Older steam turbine vessels may operate one main boiler at reduced draft to power an auxiliary turbine-generator. More commonly, an auxiliary diesel engine-generator set is used. The exact dockside power requirements vary greatly depending on the type and size of the ship and the type of cargo handling equipment on board.

The second common element among vessels in this category is the type of fuel used. The predominant fuel is oil, both distillate and residual grades, which is used in all motorships and most steamships. The trend today is for the use of heavy oil, typically Number 6 or Bunker C, in both large diesel engines and steam generators. Moderate speed diesel engines usually require a blend of distillate and residual oil for satisfactory operation. Smaller diesels, and many medium and low speed diesels operating at part throttle while maneuvering in port, require distillate oil, although a fraction of it may be residual. Other fuels are used but only to a limited extent. Wood, coal, and bagasse may be used in some very limited applications, although there appears to be some movement towards coal.* Also, nuclear powered ships are in use, although when dockside or maneuvering in port, an auxiliary power system is typically used. The number of nuclear powered vessels is small enough that no special consideration need be given them in developing the emission inventory.

The methods described below for estimating emissions do not require a significant amount of highly detailed information on the region's marine activity. The general nature of the inventorying methods presented reflects both the impracticality of developing a highly detailed accounting of vessel characteristics and activity for a particular area, and the lack of a detailed compilation of emission factors for the range of vessel types that are currently used. Further, the relative contribution by vessels to the areawide emission burden is small. As a practical matter, there is little value in expending a disproportionate share of the total inventory resources on this particular source category.

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*At least one very large coal-fired ship is being constructed by General Dynamics in Quincy, Massachusetts. This ship will use a fluidized-bed combustion system rather than the stoker used on earlier ships. When completed, this ship will be used to supply coal to electric power plants at coastal locations along the Atlantic Coast.

7.1 OVERVIEW OF METHODS

Estimates of emissions produced by marine vessels are developed using an activity factor and an emission factor. The activity factor is the estimated quantity of fuel used by vessels operating in an area. It is emphasized that the method is limited to emissions produced by fuel burned in a vessel's boilers or engines, either to move the vessel or provide power for onboard utilities (heat, lights, refrigeration, ventilation, etc.). Evaporative emissions produced during tanker loading and unloading operations, or refueling a vessel are calculated by the methods presented in Volumes II and III of this series[2,3] and are not calculated by this method.

The emission factors used are found in AP-42.[4] These factors are presented in terms of mass of pollutant produced per gallon of fuel burned by outboard and inboard motors used for recreational boating, by several types of motorships and steamships, and by auxiliary power systems operating dockside.

The methods presented here will provide a reasonable estimate of the emissions produced by marine activity in a county or urbanized area where it can be expected that this source is relatively minor (contributing less than 5 percent of the area's total for any pollutant). If a more detailed estimate of emissions from this source is required, the general procedure used is the same as described here, except that the activity factors would be derived in much greater detail. The degree that the emission estimates can be improved, however, is constrained by the general nature of the emission factors currently available.

7.2 ESTIMATING EMISSIONS FROM RECREATIONAL BOATING ACTIVITY

The approach to estimating emissions from recreational boating activity involves the application of a fuel use estimate and an emission factor. The fuel use estimate represents the total quantity of gasoline and diesel fuel consumed annually by pleasure boats. The estimates are developed separately for inboard and outboard craft.

An estimate of the quantity of fuel used by pleasure craft operating in the study area is derived indirectly by using boat registration data, a usage factor, and an activity distribution factor. This indirect approach is necessary because direct fuel sales data are not available from any government or private agency.

The first step in the process is to obtain boat registration data for the state. These data should specify the number of inboard and outboard boats and, if possible, the number of inboard boats using diesel engines and the number using gasoline engines. This information can be obtained from the agency responsible for maintaining the boat registration activity for the state, or, alternatively, estimates of the population of pleasure boats by state can be obtained from private associations, such as the National Association of Engine and Boat Manufacturers.[5] If the distribution of inboard boats by engine type is not available, a default distribution of 70 percent gasoline and 30 percent diesel can be assumed.[4]

The next step is to develop an estimate of the number of boats that are actually used in each part of the state. This is accomplished by applying the assumption that boat use is directly proportional to the surface area of water bodies available for use. The general equation for estimating the number of pleasure boats that operate in the study area is:

$$N_i = (N_s) \times (A_i/A_s) \tag{7-1}$$

where N_i = the estimated number of recreational boats that are used in area i;

N_s = the total number of recreational boats registered in the state;

A_i = the surface area of lakes, ponds, rivers, and coastal waters used for boating in area i; and

A_s = the surface area of lakes, ponds, rivers, and coastal waters used for boating in the state.

Separate values of N_i should be derived for outboard and inboard craft. Further, if a boat size (length) distribution can be determined for inboard craft, it may be useful to differentiate between water bodies where any size craft is likely to be used and those where only smaller (less than 20 feet in length) craft are used, and to allocate usage separately for these two size categories of inboard craft.

The total surface area of water bodies within the state, A_s, and within the study area, A_i, can be derived by direct measurement from a suitably scaled map, or can be obtained from a publication entitled Area Measurement Reports--Areas of (Specified State),[6] published by the Bureau of the Census,* which reports surface area measurements of land, water, and total area for each county or other civil division. Whether Bureau of the Census data or measured data are used, coastal waters must be included. The area of coastal water is derived by measurement, and applying the assumption that the area's outer limit extends 1 mile out from and parallel to the shore line. There is no formal method for differentiating between water facilities limited to boats smaller than 20 feet and areas available to all pleasure craft. This differentiation must be accomplished subjectively, although general assumptions used should be based on some knowledge of the water facilities.

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*Although these documents are currently out of print and therefore not available from the Bureau, copies can be found in libraries.

It is reasonable to assume that the use of larger inboard craft will be limited to major rivers, large lakes, and coastal waters, whereas the smaller inboard craft and all outboard boats will be used on any water body were power boating is permitted. The result is an estimate of the number of boats in each of two or three categories (outboard and inboard, or with inboards further categorized by two size classes) that operate within each study area.

The next step is to derive an estimate of the quantity of fuel used by each category of boat. The equation for the quantity of fuel used annually by motor boats of any type is:

$$Q_{ij} = N_{ij} \times f_j \times C \qquad (7\text{-}2)$$

where Q_{ij} = the annual quantity of fuel, in gallons, used by boat category j in area i;

N_{ij} = the number of category j boats used in area i, from Equation (7-1);

f_j = a fuel consumption factor, in gallons per hour, for category j boats; and

C = a usage factor describing the expected annual hours of operation of recreational boats.

The fuel consumption factor used is either 1.5 gallons per hour for outboard engines or 3.0 gallons per hour for all inboard engines.[7,8,9] The usage factor, C, is dependent on the geographic location of the area and is found by:

$$C = 10 \times M \qquad (7\text{-}3)$$

where 10 = the assumed number of hours per month of recreational boat operation; and

M = the number of months per year during which the monthly mean temperature exceeds 45°F for areas north of 43° latitude, 48°F for areas between 37° and 43° latitude, and 55°F for areas south of 37° latitude.

The value of M for a particular area is obtained from climatological data published by the U.S. Department of Commerce.[10]

The quantity of fuel for inboard boats, computed from Equation (7-2), will reflect the total combined gasoline and diesel usage. At this point, estimates of the quantity of each type of fuel must be made. This is accomplished by using either data obtained from boat registration statistics or default values. If registration data are available indicating the distribution of gasoline and diesel craft by size, the estimated quantities of gasoline and diesel fuel used in the area should be based directly on this distribution--that is, if P percent of inboard craft under 20 feet in length are diesel powered, then P percent of the total quantity of fuel used by inboard boats less than 20 feet in length is assumed to be diesel, while (100-P) percent is gasoline. If the registration data only indicate the percent of total craft that are diesel, then it should be assumed that all craft under 20 feet are gasoline powered; therefore, only fuel used by the larger inboard craft will be separated into diesel and gasoline components (using the same method described previously). If no registration data are available regarding the percentage of diesel- and gasoline-powered boats, and separate estimates were developed for fuel used by large and small inboard boats, assume that all of the smaller inboards are gasoline powered, and that 30 percent of the large inboards are diesel while the remaining 70 percent are gasoline powered. If no data on the distribution of engine types are available and no distinction was made between large and small inboard craft, assume that 15 percent of the total fuel used by inboards is diesel and 85 percent is gasoline. In any event, assume that all fuel used by outboard craft is gasoline. Depending on the level of detail applied, one of the following sets of fuel use data will be developed:

Set 1: Gasoline used by outboards,
Gasoline used by small inboards,
Gasoline used by large inboards,
Diesel used by small inboards, and
Diesel used by large inboards.

Set 2: Gasoline used by outboards,
Gasoline used by small inboards,
Gasoline used by large inboards, and
Diesel used by large inboards.

Set 3: Gasoline used by outboards,
Gasoline used by inboards, and
Diesel used by inboards.

The final step is to compute emission estimates. This requires the application of an emission factor for each pollutant to the quantity of fuel consumed, or:

$$E_{ijp} = Q_{ij} \times EF_{jp} \qquad (7\text{-}4)$$

where E_{ijp} = the quantity of emissions of pollutant p, produced annually in area i, by category j boats;

Q_{ij} = the quantity of fuel used in area i by category j boats; and

EF_{jp} = the emission factor for pollutant p for category j boats.

The emission factors, EF_p, for each type of boat are included in Table 7-1.

TABLE 7-1. AVERAGE EMISSION FACTORS FOR RECREATIONAL BOATS

Pollutant[a]	Gasoline-powered outboard motors ($lb/10^3$ gal)	Gasoline-powered inboard motors ($lb/10^3$ gal)	Diesel-powered inboard motors ($lb/10^3$ gal)
SO_2	6.4	6.4	27
CO	3300	1240	140
HC	1100	86	180
NO_2	6.6	131	340

[a] Particulate emissions are considered negligible.

Source: Reference 4, AP-42, Tables 3.2.3-5 and 3.2.4-1.

The total emissions produced by pleasure craft is the aggregate of emissions produced by each of the individual categories.

7.2.1 TEMPORAL DISTRIBUTION OF EMISSIONS

Recreational boating activity is highly seasonal with the most activity occurring during the summer. Monthly variations in boating activity can be estimated based on inquiries made to marinas or boating clubs, or it can be assumed that 75 percent of the activity occurs during the months of June, July, and August. Further, it can be assumed, in the absence of actual data, that the average daily activity during the peak week of the summer is equal to 1.5 percent of the total annual activity, as measured by fuel use.

7.3 EMISSIONS FROM COMMERCIAL VESSELS

Two methods are available for estimating emissions from commercial and military vessels. The first method is based on the quantity of fuel sold for marine use, from which emissions are estimated using a standard set of assumptions regarding the percentage of fuel sold that is actually used within the port area, and the emission rate associated with the use of the fuel. The second method attempts to provide a more accurate estimate based on ship movement data. Both methods are described here.

7.3.1 FUEL SALES METHOD

Sales data for residual and distillate fuel oil used for marine purposes are compiled by the U.S. Department of Energy and published annually as state summaries.[11] To apportion state fuel sales to a particular harbor or port, the relative level of activity within the harbor must be established. To do this, an inventory of vessel activity must be obtained for both the harbor and statewide. Such an inventory is published by the Corps of Engineers in Waterborne Commerce of the United States.[12] In Part 2 of that document, a table is provided for each port within a state, indicating the number of commercial vessels, by size (draft), that enter and leave.

In apportioning total statewide marine fuel sales, distillate fuel and residual fuel are considered separately. To apportion residual fuel, the assumption is made that only vessels with a draft of 18 feet or more use residual oil. The apportioning factor for residual oil sold in port i is:

$$f_{ri} = (N_{i \geq 18})/(N_{s \geq 18}) \qquad (7\text{-}5)$$

where F_{ri} = the apportioning factor for residual fuel used in port i,

$N_{i \geq 18}$ = the number of vessels using port i with a draft of 18 feet or greater, and

$N_{s \geq 18}$ = the total number of vessels using all ports within the state with a draft of 18 feet or more.

The estimated quantity of residual oil sold in port i is computed as the product of the statewide marine fuel sales, in gallons or barrels, and the apportioning factor, f_{ri}.

The quantity of distillate oil sold in port i is estimated in a similar fashion. The Waterborne Commerce of the United States[12] document is used to determine the total number of vessels with drafts of 18 feet or more and those with drafts of less than 18 feet, using port i, and the total number of ports within the state. The apportioning factor for distillate fuel in port i is:

$$f_{di} = [(N_{i<18}) + 2(N_{i \geq 18})]/[(N_{s<18}) + 2(N_{s \geq 18})] \qquad (7\text{-}6)$$

where f_{di} = the apportioning factor for distillate fuel sold in port i,

$N_{i<18}$ = the number of vessels with less than 18 feet of draft using port i,

$N_{i \geq 18}$ = the number of vessels with 18 feet or more of draft using port i,

$N_{s<18}$ = the number of vessels with less than 18 feet of draft using all ports within the state, and

$N_{s \geq 18}$ = the number of vessels with 18 feet or more of draft using all ports within the state.

In Equation (7-6), larger vessels (i.e., those drawing 18 feet or more) are weighted by a factor of 2, which accounts for both the greater quantity of fuel used by these vessels while moving, and the use of auxiliary power generation systems by these larger vessels while at dockside. The estimated quantity of distillate fuel sold in port i is the product of the total distillate fuel sold in the state for marine use and the apportioning factor, f_{di}.

All of the fuel sold in port i is not used there. An assumption can be made, however, that 25 percent of the residual oil and 75 percent of the distillate oil sold in port i is used there. This is based on methods developed by the U.S. Environmental Protection Agency.[7] The total estimated quantities of residual and distillate oil used in port i are:

$$Q_{ri} = 0.25 \times f_{ri} \times Q_{rs} \quad \text{for residual, and} \qquad (7\text{-}7a)$$

$$Q_{di} = 0.75 \times f_{di} \times Q_{ds} \quad \text{for distillate} \qquad (7\text{-}7b)$$

where Q_{ri} and Q_{di} = the quantities of residual and distillate oil, respectively, used in port i;

f_{ri} and f_{di} = the apportioning factors for residual and distillate oil, computed from Equations (7-5) and (7-6), respectively; and

Q_{rs} and Q_{ds} = the total quantities of residual and distillate oil sold in the state for marine use, from Reference 11.

To estimate emissions, an emission factor is applied to the quantities Q_{ri} and Q_{di}. These emission factors are found in AP-42[4] and are reproduced here in Table 7-2 for motor vessels and Table 7-3 for steamships. In Table 7-2, emission factors are given for three general categories of vessels--River, Great Lakes, and Coastal; they are, however, nearly identical. An assumption can be made that all distillate oil is used by motorships, while all residual oil is used by steamships.

7.3.2 SHIP MOVEMENT DATA METHOD

This method utilizes data concerning the number of vessels in various size categories that use a particular port, assumptions about dockside activity, and ship movements in and out of the harbor.

The first data element required is the number of vessels, by size category, using the port. Two size categories are of interest--vessels with a draft of less than 18 feet and vessels with a draft of 18 feet or more. This information can be obtained directly from Reference 12. These data are used to compute emissions for vessels underway and vessels at dockside.

TABLE 7-2. AVERAGE EMISSION FACTORS FOR COMMERCIAL MOTORSHIPS BY WATERWAY CLASSIFICATION

Pollutant	Emission factors		
	River	Great Lakes	Coastal
Sulfur oxides			
kg/10^3 liter	3.2	3.2	3.2
lb/10^3 gal	27	27	27
Carbon monoxide			
kg/10^3 liter	12	13	13
lb/10^3 gal	100	110	110
Hydrocarbons			
kg/10^3 liter	6.0	7.0	6.0
lb/10^3 gal	50	59	50
Nitrogen oxides			
kg/10^3 liter	33	31	32
lb/10^3 gal	280	260	270

Source: Reference 4--Emission factors in AP-42 are subject to revision; the above factors should be checked before use to ensure that they are current.

TABLE 7-3. AVERAGE EMISSION FACTORS FOR COMMERCIAL STEAMSHIPS

Pollutant	Emission factors[a] (lb/10^3 gal)
Particulates	10.0
Sulfur oxides	159 x (fuel sulfur content, in percent)
Carbon monoxide	Negligible
Hydrocarbons	3.2
Nitrogen oxides	36.4

[a] For commercial steamship hoteling.

Source: Reference 4--Emission factors in AP-42 are subject to revision; the above factors should be checked before use to ensure that they are current.

7.3.2.1 Underway Emissions

Underway emissions occur while the vessel is entering, leaving, or maneuvering in port. Estimates of the quantity of emissions produced by underway vessels can be developed by estimating the average travel time by vessels entering, maneuvering, and leaving the port, applying a fuel consumption factor, and applying an emission rate based on the quantity of fuel used.

Vessels with a draft of less than 18 feet are assumed to be powered by diesel engines and use only distillate oil, while those vessels with a draft of 18 feet or more are assumed to be either diesel or steam powered. Although large diesel-powered vessels are capable of burning residual oil, it is assumed that distillate is used while underway or maneuvering in port. Further, it is assumed that all steamships use residual oil at all times.

To estimate average travel time, the distance between the outer limits of the study area and a theoretical centroid of activity within the port is determined. This distance is increased by 120 percent to account for maneuvering and leaving port, and divided by an assumed average speed in port of 8 miles per hour to yield the estimated average underway travel time of each vessel using the port. This is:

$$\bar{t} = (2.2d)/8 = 0.275d \qquad (7\text{-}8)$$

where $\bar{t}$ = average travel time for vessels using the port, and

d = the distance in statute miles between the outer limit of the study area and the assumed centroid of port activity.

Fuel consumption rates for vessels operating in port are provided in Table 7-4. Different rates are given for motorships and steamships. The method used to derive the distribution of motor vessels and steamships involves determining the relative number of American and foreign registered vessels, since essentially all large American vessels are steam powered while most foreign vessels are powered by diesel engines. This information can be obtained from the port authority or Coast Guard station having jurisdiction.

Once fuel use associated with underway operations has been computed, emissions can be calculated by applying emission factors from Table 7-5. Emissions are calculated from:

TABLE 7-4. FUEL CONSUMPTION RATES IN GALLONS PER HOUR FOR VESSELS OPERATING IN PORT AREAS

Vessel size (draft in feet)	Fuel consumption rate (gal/hr)	
	Motor vessels	Steamships
<6	5	-
≥6 <12	10	-
≥12 <18	44	-
≥18	128	160

Source: Reference 13.

TABLE 7-5. EMISSION FACTORS FOR VARIOUS GENERAL CATEGORIES OF VESSELS OPERATING IN PORT AREAS

	Emission factors ($lb/10^3$ gal) by vessel size (draft in feet)				
	Motor vessels				Steamships
Pollutant	<6[a]	≥6 <12[b]	≥12 <18[c]	≥18[d]	≥18[e]
Carbon monoxide	47.3	99.7	62.2	110.0	3.5
Hydrocarbons	51.1	44.5	16.8	50.0	0.7
Nitrogen oxides	389.3	338.6	167.2	270.0	55.8
Sulfur oxides	27.0[d]	27.0[d]	27.0[d]	27.0	159 x (fuel sulfur content, in percent)
Particulates	-	-	-	-	20.0

[a] 300-hp engine, cruise mode.

[b] 500-hp engine, cruise mode.

[c] 900-hp engine, 2/3 mode.

[d] Coastal vessels.

[e] Residual oil, cruise mode.

Source: Reference 4.

$$E_{ijp} = Q_{ij} \times EF_{jp} \qquad (7\text{-}9)$$

where E_{ijp} = the quantity of emissions of pollutant p produced annually by category j vessels operating within area i waters;

Q_{ij} = the quantity of fuel, in gallons, consumed by vessel type j; and

EF_{jp} = the emission factor for pollutant p and vessel type j, from Table 7-5.

7.3.2.2 Dockside Emissions

Large vessels (i.e., those with a draft of 18 feet or more) produce emissions while dockside since either auxiliary diesel generator systems or the main boilers are operated to supply power for the vessels' utilities. Further, the boilers on most steamships in port for less than 2 days are rarely shut down because of the relatively long time required to restart and prepare them for operation. To estimate the quantity of emissions produced by these vessels, an estimate of the average number of days in port must be developed and a fuel consumption rate determined. After the total quantity of fuel consumed in port is estimated, an emission factor is applied to derive the actual emission estimate.

The average duration of stay for large commercial vessels is between 1 and 3 days. An estimate for a particular port can be derived by inquiring to the port authority, Coast Guard, or shipping company, or a default value of 3 days can be used.

The fuel consumption rates for steamships and motor vessels are assumed to be 1900 gallons per day of residual oil and 660 gallons per day of distillate oil, respectively.[13] Again, the assumption is that all American vessels are steamships while foreign vessels are motorships. Fuel used by each type of vessel while in port is calculated from:

$$Q_{ijk} = N_{ij} \times D_{ij} \times f_j \qquad (7\text{-}10)$$

where Q_{ijk} = total annual fuel consumption of fuel type k (either residual or distillate oil), in area i, by type j vessels;

N_{ij} = total number of type j vessels (either steamships or motorships)using the port;

D_{ij} = average duration of stay for vessel type j in area i; and

f_j = fuel consumption rate for vessel type j (assumed to be 1900 gallons per day of residual oil for steamships and 660 gallons per day of distillate oil for motor vessels).

Emissions produced by the ships while at dockside are:

$$E'_{ijp} = Q'_{ij} \times EF'_{jp} \qquad (7\text{-}11)$$

where E'_{ijp} = the quantity of emissions of pollutant p produced annually by category j vessels while at dockside in area i waters;

Q'_{ij} = the quantity of fuel, in gallons, consumed at dockside by vessel type j; and

EF'_{jp} = the emission factor for pollutant p and vessel type j, from Table 7-6.

TABLE 7-6. EMISSION FACTORS FOR VESSELS AT DOCKSIDE

	Emission factors ($lb/10^3$ gal)	
Pollutant	Motorships	Steamships[a]
Particulates	Negligible	10.0
Sulfur oxides	27	159 x (fuel sulfur content, in percent)
Carbon monoxide	44[b]	Negligible
Hydrocarbons	59[b]	3.2
Nitrogen oxides	364[b]	36.4

[a] Residual oil used for hoteling mode.

[b] 500-KW generator operated at 75 percent rated output.

Source: Reference 4.

7.3.3 TEMPORAL DISTRIBUTION OF EMISSIONS

To identify seasonal variations in emissions, monthly tabulations of vessel activity can be obtained from the local port authority.

References for Chapter 7.0

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